# The Journal of Bone and Joint Surgery

*The Official Publication of*
The American Orthopaedic Association
The British Orthopaedic Association
The American Academy of Orthopaedic Surgeons
The Australian Orthopaedic Association
The Canadian Orthopaedic Association
American Society for Surgery of the Hand
New Zealand Orthopaedic Association
South African Orthopaedic Association

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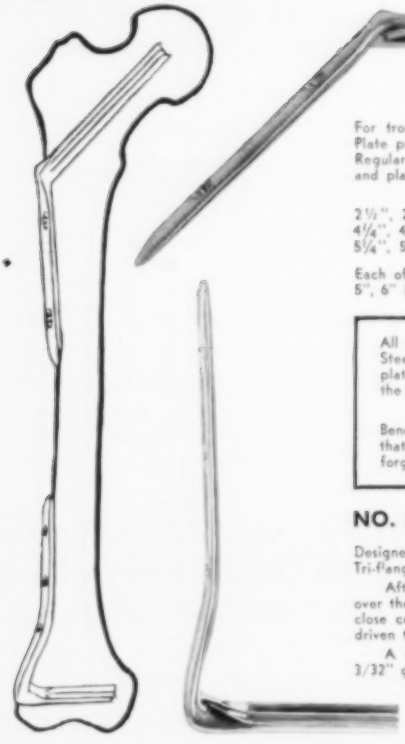

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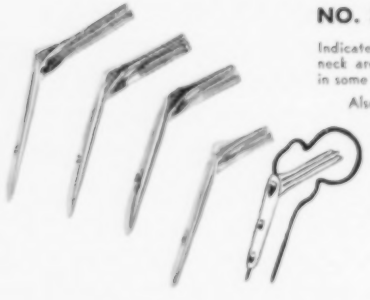

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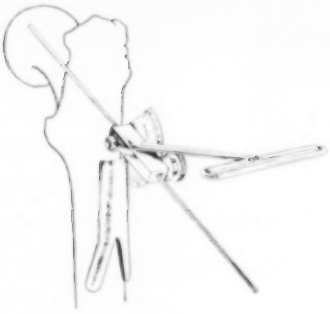

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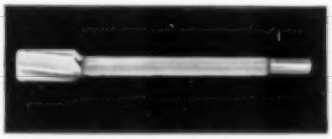

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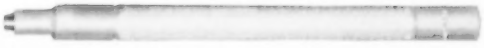

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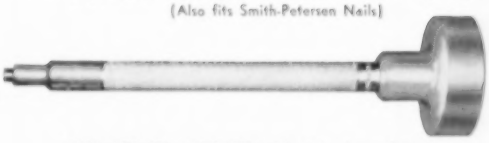

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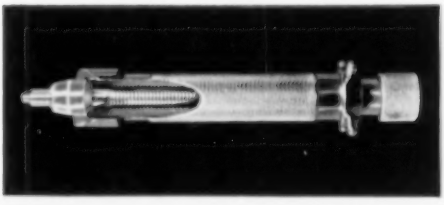

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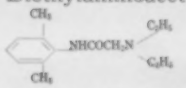

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**Versatility** : Effective in local infiltration anesthesia; in major conduction anesthesia; in temporary therapeutic blocks for relief of pain; in topical anesthesia.

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**Supplied** : Vials, 0.5%, 1% and 2% in 20 cc. and 50 cc. without and with epinephrine 1:100,000; 100 cc. vials, 1% without epinephrine. Ampoules, 2 cc., 2% without and with epinephrine 1:100,000.

**Astra Pharmaceutical Products, Inc., Worcester 6, Mass.**

*U. S. PATENT NO. 2,441,498

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*Successfully used in the treatment of:*

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*And many other conditions requiring steady or intermittent traction.*

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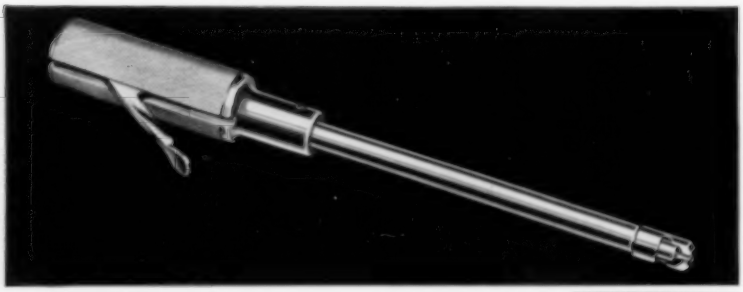
1. Spies, T. D., et al.: GP 12:73, No. 1, 1955. 2. Boland, E. W.: J.A.M.A. 160:613, 1956. 3. Gillhespy, R. O.: Lancet 2:1393, 1955.

PFIZER LABORATORIES Division, Chas. Pfizer & Co., Inc. Brooklyn 6, New York

# NEW IMPROVED SCREW DRIVER *by Orthopedic*



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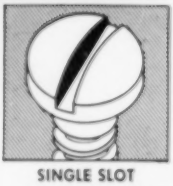

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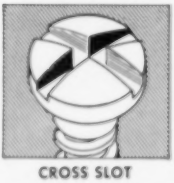

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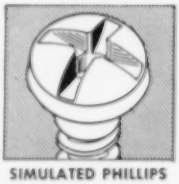

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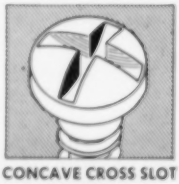

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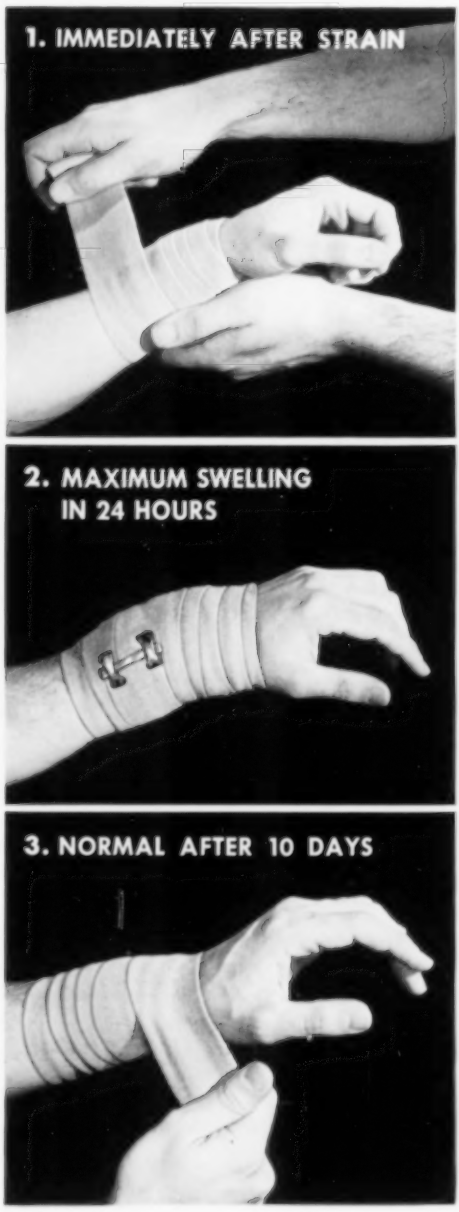


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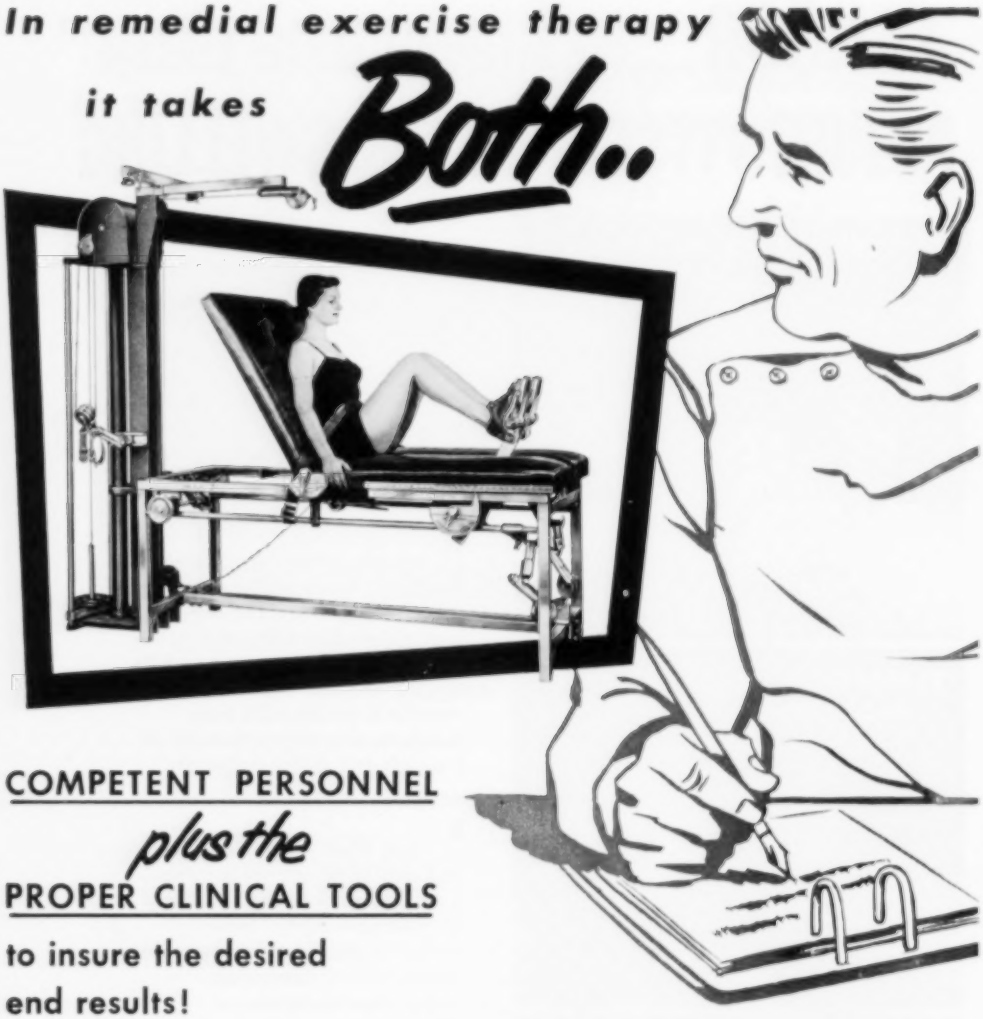

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References: 1. Hollander, J. L., Ann. New York Acad. Sc. **61**:511, May 27, 1955.
2. Hollander, J. L., *et al.* J.A.M.A. **158**:476, June 11, 1955.

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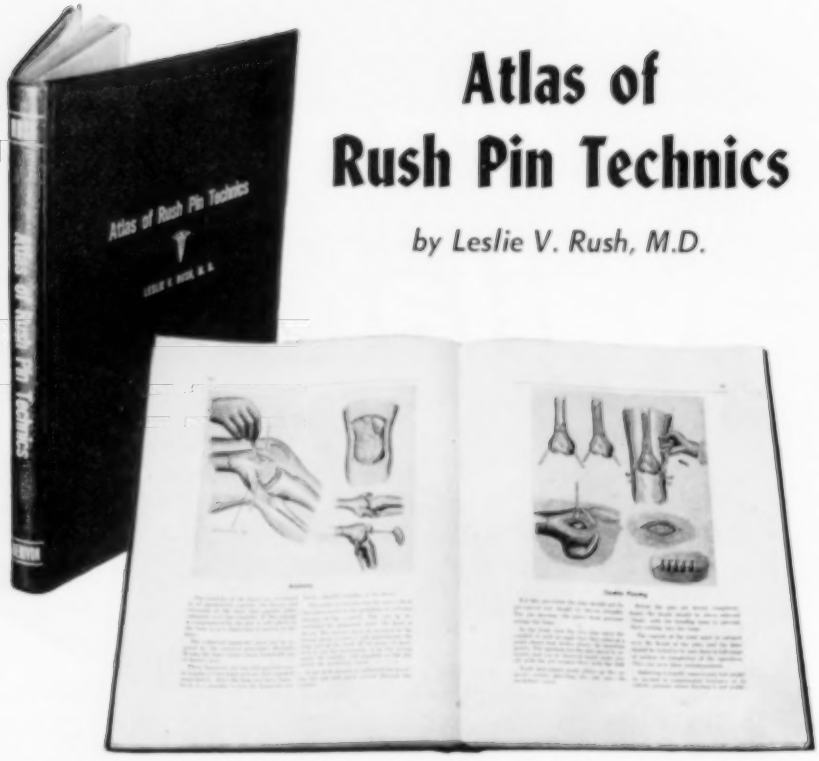


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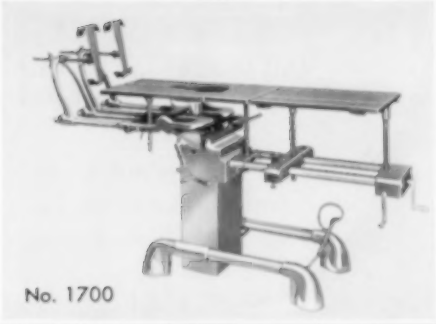

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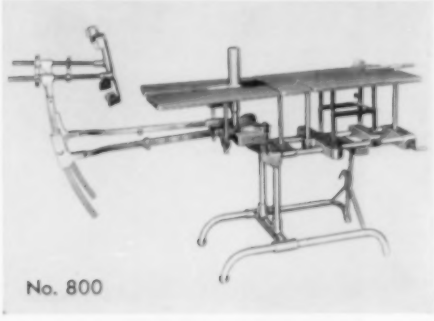

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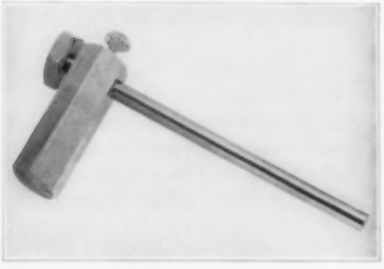

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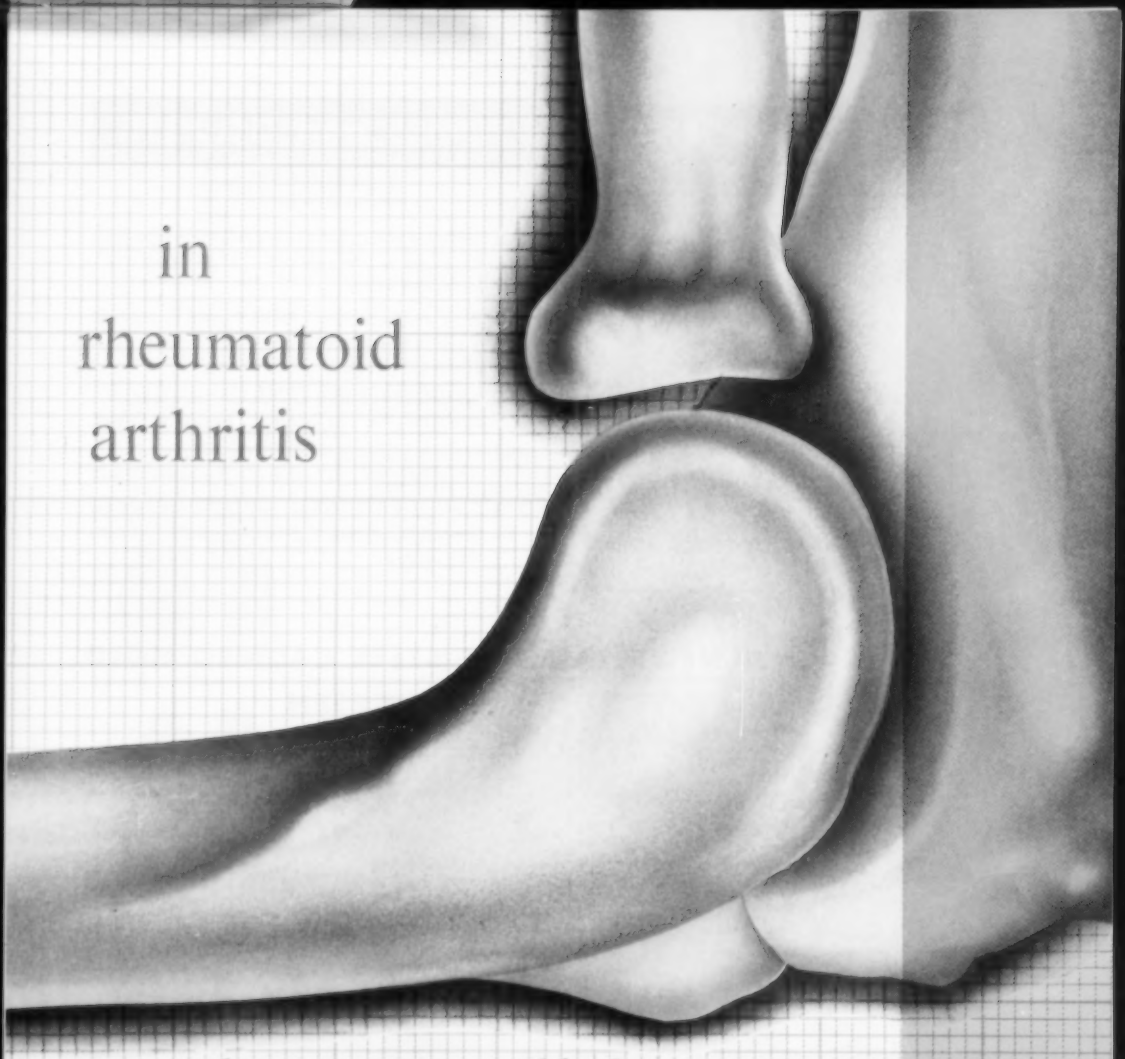

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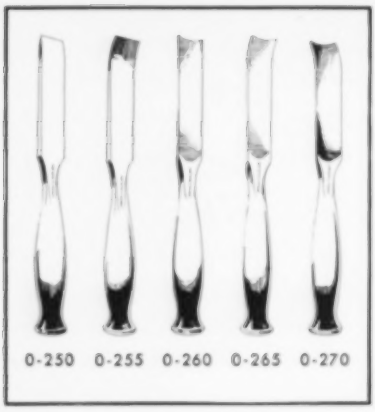

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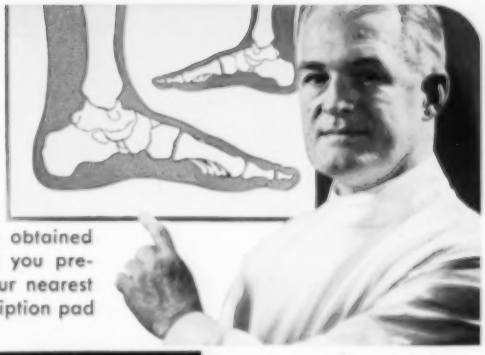

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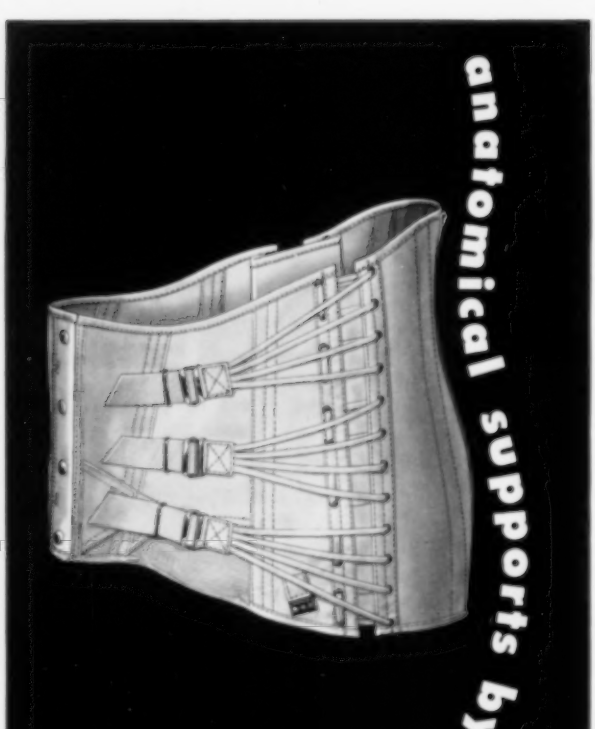


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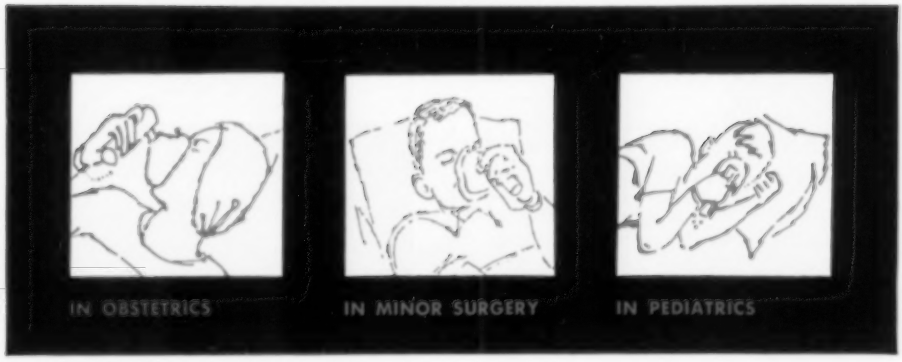


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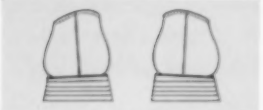

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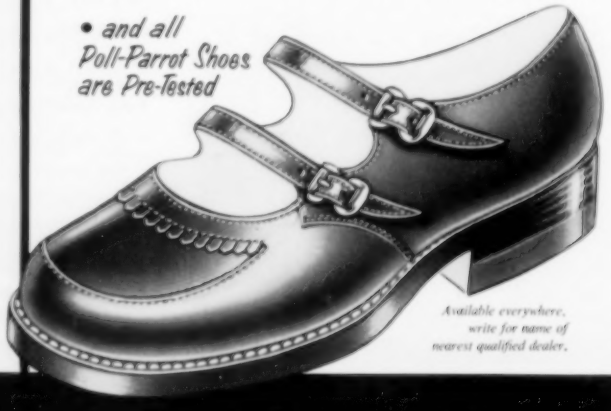

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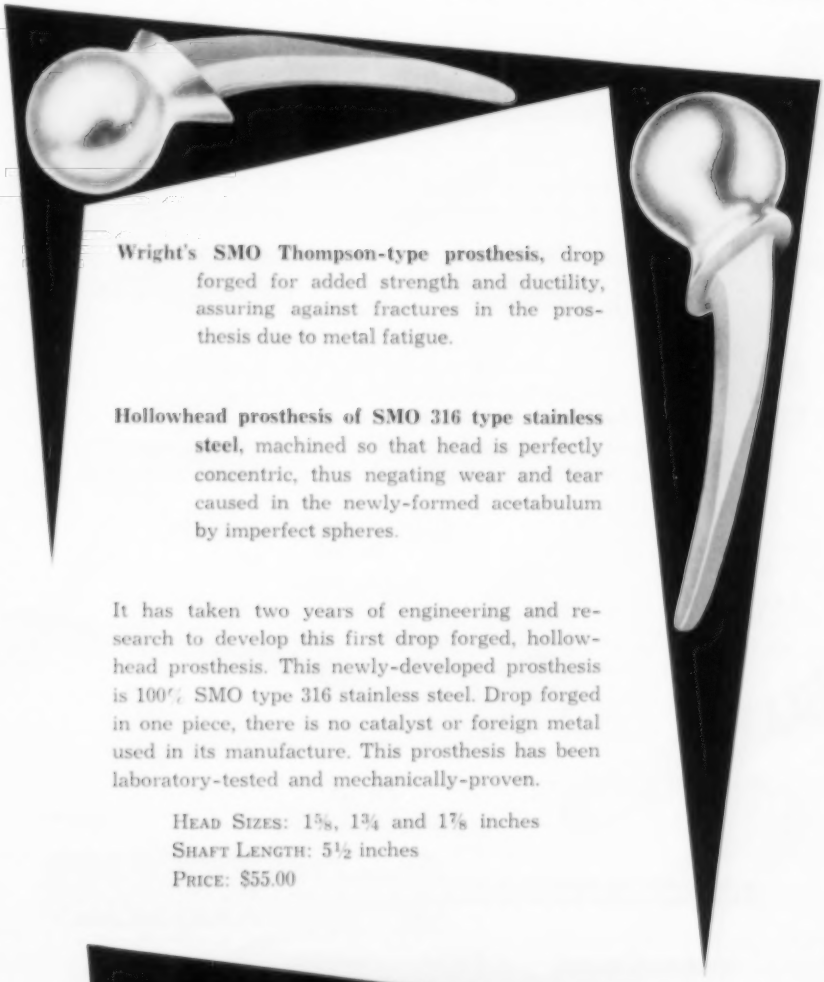

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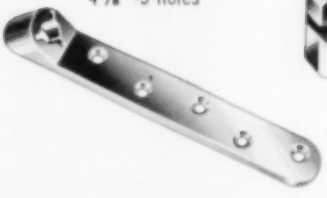

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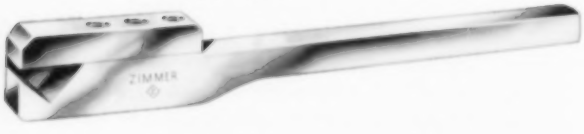


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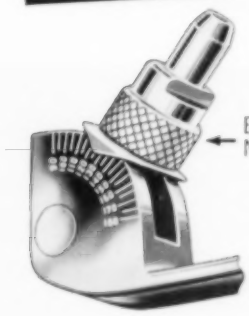

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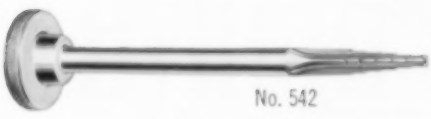

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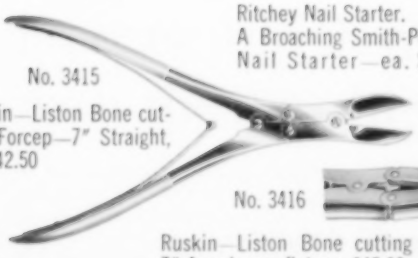

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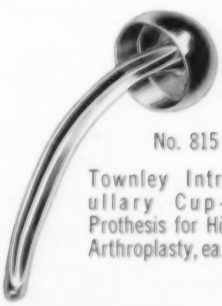

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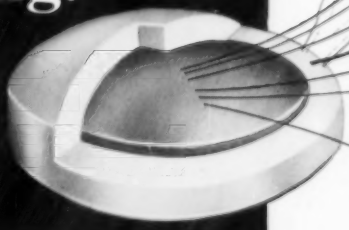

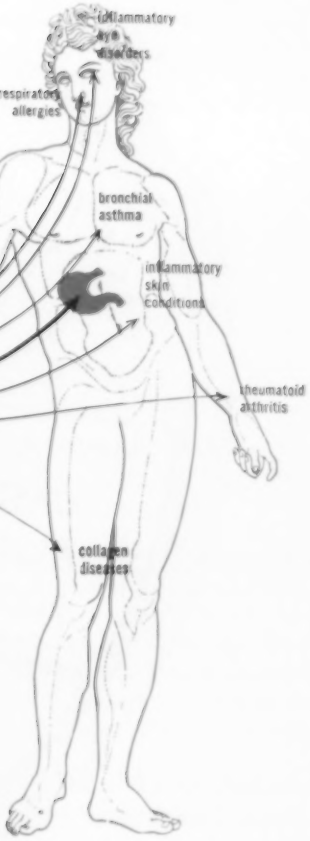


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The Journal of
Bone and Joint Surgery
*American Volume*

# Functional Bracing of the Arm *

PART I

BY EDWIN R. SCHOTTSTAEDT, M.D., SAN FRANCISCO, CALIFORNIA,
AND GEORGE B. ROBINSON, PROSTHETIST, VALLEJO, CALIFORNIA

*From the Department of Orthopaedic Surgery, University of California School of Medicine and the May T. Morrison Rehabilitation Center, San Francisco*

As the result of an opportunity, in 1947, to care for the sequelae of poliomyelitis at the May T. Morrison Center for Rehabilitation our interest in the general subject of functional bracing of the arm was stimulated by several survivors of the respirator who had either severe unilateral or severe bilateral upper-extremity paralysis. The various apparatuses in use at that time have been improved. An appraisal of the equipment available at the present time and of the principles involved in its use seems important, so that the use and development of such equipment may become more widespread. The worth of such equipment is unquestioned in properly selected cases.

The principles of upper-extremity bracing are different from those of lower-extremity bracing. This is necessarily true since lower-extremity bracing is designed to aid in supplying function to the lower extremities. The replaceable lower-extremity function is stability with transportation of the body from place to place, as in standing, walking, climbing stairs, hills, and ramps, and mounting and dismounting from trains, streetcars, and automobiles. For these purposes hinged metal supports have been made which stabilize the foot in dorsiflexion and stabilize the knee and hip in extension. Ischial rings have been used to prevent weight-bearing on soft bone or to supplant partly the gluteal abductor muscles. Lower-extremity braces must necessarily be sturdy enough to withstand the heavy stresses and strains placed upon them, although they must remain light enough to allow function. In spite of this, the braces tend to become relatively massive structures even with the use of light metals. Functional bracing of the arm, however, is designed to replace or to facilitate normal upper-extremity function. Upper-extremity function demands maximum mobility and minimum weight of apparatus. The upper extremity is primarily important to us for such light activities as self-feeding and toilet care (washing hands and face, brushing teeth, combing hair, applying cosmetics, and dressing). The upper extremity is used also in writing, in preparing food, and in a multitude of self-care activities which most of us accept in our daily lives without a second thought. In addition to these basic light activities, there are other heavy-duty activities, such as getting in and out of bed, on and off a toilet seat, and in and out of a chair or wheel chair. Even if there is no associated lower-extremity weakness, there is need for greater strength in the upper

* Read at the Annual Meeting of The American Orthopaedic Association, White Sulphur Springs, West Virginia, June 19, 1955. The material on which this paper was based was presented as a Scientific Exhibit at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 28 to February 2, 1956.

extremities in order to hold and to carry articles of varying sizes, weights, and shapes. As a final replacement of upper-extremity function, there are all the duties of industry and the farm—the myriad functions and the strength necessary in earning a living in a competitive labor market.

As yet, in arm bracing light and moderate replacement is chiefly attempted, since available motors are usually insufficient with the present apparatus and holding devices to accomplish heavy-duty work. However, a problem involving heavy duty can be solved for a patient when the opposite arm is normal and when there is only minimal loss in the affected arm which needs to be replaced, for example, a hook for a hand. Primarily then, the problem of lower-extremity bracing is one of static body support to aid in movement from place to place; the problem in the upper extremity is one of motion, for the normal arms are mobile units carrying a complex grasping device into position to accomplish grasping or some associated act.

The following types of arm bracing have previously been available but are for the most part in the nature of static equipment.

1. Braces to prevent deformity:
   a. Shoulder abduction braces which maintain the arm in a fixed degree of abduction;
   b. Cock-up wrist splints applied to the volar surface of the forearm and hand;
   c. Opponens holding splints applied to the thumb web;
   d. Articulated hand braces adjusted to varying finger and hand positions but intended for use as holding supporting splints.
2. Braces fixing position in order to obtain optimum functional working conditions:
   a. Cock-up wrist splints which are applied to the dorsal surface and which are made so that the volar surface of the hand is free;
   b. Spring opponens clip braces made to leave the palm and the thumb web free;
   c. Banjo splints which suspend the fingers in some extension to allow active finger flexion (the Warm Springs group has made the greatest contribution in this category).
3. Braces designed to correct deformity:
   a. Turnbuckle elbow braces to force extension;
   b. Spring braces to stretch pronation and supination;
   c. The excellent hand braces of Bunnell.

All of these types have many applications and modifications. They are extremely important in redeeming and preserving functional upper-extremity units; but they, as a group, are directed toward gaining or maintaining effective working length of muscle-tendon units and the correction or prevention of contractures of the upper-extremity joints. Functional bracing of the arm has as its primary purpose the restoration of active upper-extremity use with a return to as near normal function as possible. Of course, the optimum goal will seldom be obtained, but the maximum return for a given extremity should be sought. The brace should be as important to the patient in function as an arm prosthesis is to the amputee. The brace may be used in the following circumstances:

1. To supplant completely lost upper-extremity function;
2. To assist or to supplement lost upper-extremity motor power;
3. To supplement surgical reconstruction.

Functional bracing of the arm, in order to be practical, must be made-to-order for each individual patient after a careful appraisal of his remaining motor power and a detailed analysis of his most pressing needs. The brace is best prescribed by the team approach now in use for prosthetic prescription for the arm, although such a course is not essential. However, a careful appraisal of self-care activities by an occupational therapist and a physical therapist is valuable as a foundation for discussion. Once the needs of the patient are recognized by the patient, therapist, prosthetist, and physician, an intelligent prescription may be written. This will, of course, depend upon the motors available. In

the severely paralyzed extremity, no one brace will ever supply all of the lost function. The degree of remaining function will determine the working range which can be regained. Thus, it is important to know the working range for the activities to be replaced in order that we may know whether we may expect to replace them. For the wheel-chair patient with severe upper-extremity paralysis, this range will be close to the body and will consist of work on a table or on a board placed upon the wheel-chair arms. It will be important for the patient to be able to reach his face and desirable to give the patient assistance in dressing and undressing. Upper-extremity usefulness in accomplishing most needed activities depends upon bringing things to the body or upon placing them away from the body. Certain movements are helpful but are not necessarily essential to these tasks; other movements are absolutely essential. The patient must first have a grasping hand or a grasping device. If he has one good hand, the device may be merely necessary for holding objects so that the other hand can have something to work against. If neither hand is suitable for grasping (picking-up and holding), then at least one extremity with a working hand should be provided. This may mean the use of a functional hand brace or, perhaps, substitution with a hook. Once grasp, or some component of grasp, has been obtained, the normal strength remaining in the arm will make it useful. If there is no strength remaining, the various component arm functions will need replacement. It is apparent to most of us that wrist flexion and extension are not essential movements; these are indeed often bypassed by arthrodesis of the wrist. In bracing of the arm, the flail wrist is usually best stabilized in the most functional position. Although wrist motion is very useful, it is certainly not essential. The problem of the individual patient should be carefully evaluated, for available wrist motors, properly harnessed, will materially improve the functional result of both the Handy Hook or the functional hand brace. Pronation and supination, active or passive, is not essential for all activities, but it is a "must" for an appliance which is to have general replacement usefulness. Elbow flexion and extension are even more essential for successful bracing of the arm. Gravity will succeed in providing elbow extension in many situations, but the ability to flex and to extend the elbow is second in importance only to the ability to grasp. Internal and external rotation of the shoulder are also important. They are akin to pronation and supination, although, if anything, they are more important in upper-extremity function. Shoulder abduction is useful but is much less essential. If the shoulder is pre-positioned in slight flexion, a large number of activities are easily engaged in without abduction. Slight shoulder flexion of 5 to 10 degrees is extremely important. This may be attained actively by means of a spring arrangement, or shoulder flexion may be statically pre-positioned by means of a fixed-position brace with an arm cuff. Shoulder flexion is necessary, since the hand cannot be brought to the face, despite all other motions, if the upper arm lies directly at the side or falls slightly behind the coronal plane. Isolated scapulothoracic function (scapular elevation or forward scapular flexion) is less important than other motions in the severely involved upper extremity, except that it is especially valuable and often essential as a source of motor power. (See section on harnessing.)

In summary, the functional movements of the upper extremity in the order of their importance are: grasp or some component of it, elbow flexion and extension, internal and external rotation of the shoulder, and pronation and supination of the forearm. A patient can get along satisfactorily without wrist motion, shoulder abduction, shoulder elevation, or forward shrug, and with only slight shoulder flexion. In the evaluation of a patient's need, plans must be made to supply those movements lacking or requiring supplementation. With the continued development of braces, the details of supplying the less essential features of shoulder motion will undoubtedly be solved, and the working area will be increased.

Before discussing special features in equipment, certain fairly obvious points that were occasionally overlooked in early prescriptions should be emphasized. A brace to be

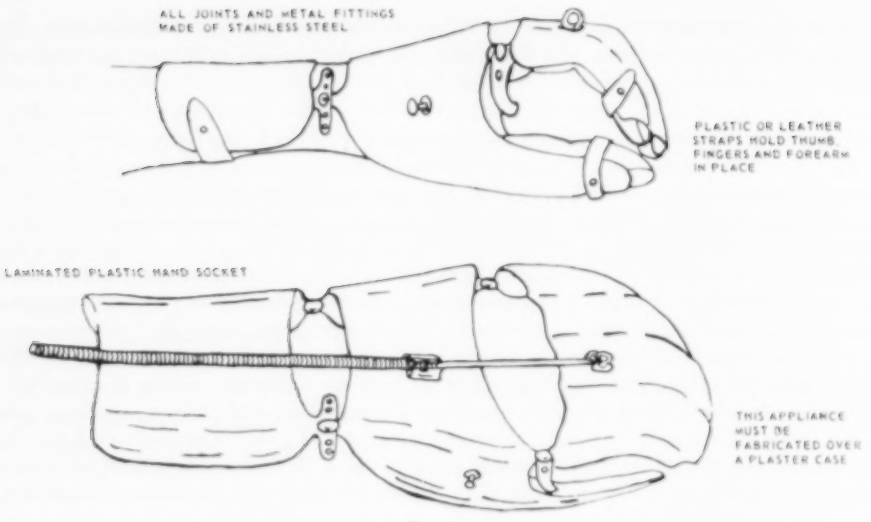

ALL JOINTS AND METAL FITTINGS MADE OF STAINLESS STEEL
PLASTIC OR LEATHER STRAPS HOLD THUMB, FINGERS AND FOREARM IN PLACE
LAMINATED PLASTIC HAND SOCKET
THIS APPLIANCE MUST BE FABRICATED OVER A PLASTER CASE

FIG. 1

Basic construction of the Handy Hand: dorsal and radial views.

useful must have a point of fixation to the body. A hook attached to a hand, operated by shoulder elevation is useless if the rest of the arm is flail and is not supported by apparatus. The hook may open and grasp objects, but these not only cannot be transported from their original location but they will not even hold their position against force from the other hand, for when the good hand applies force against them the object will be pushed away. A stationary table vise, operated by the other hand, is of more value than such floating equipment. There must be a source of motor power that can be rerouted in order to accomplish the desired activity. A leg and foot may be used to supply hand and elbow motion, and head rotation may supply the power to open a hook. Thus a source of motor power must be available. It should also be remembered that if elastic motor power is to be used in order to accomplish a motion, the elastic motor must have an opposing muscle pull. In other words, if elbow flexion is to be supplied by elastic motor power, some other motor must provide elbow extension; this power will necessarily be greater than gravity alone. At present this is provided by the triceps. However, gravity may be sufficient to supply elbow extension if elastic power is used to supplement existing weak elbow flexors, although even in such an instance active elbow extension will make the apparatus more versatile. Gravity may also act as the opposing force, if the elbow flexion supplied receives its power from a distance, as is the case with a reciprocator.

Any motor must have a fixed point from which to work. This point must maintain some fairly constant fixed length relationship to the motion desired. It may be adjustable by the patient, as it is with the use of a reciprocator, to different length situations; but in order to provide motion at a distance, it is necessary that the active motor work through a definite limited range and against a fixed point. The apparatus must not be so bizarre that the patient will not wear it. It must be relatively simply activated; it must not be beyond the ability of the patient to operate. Such apparatus must not be too complicated for what it accomplishes and it must not be uncomfortable. The patient should, if possible, be able to put it on and to take it off, although this is not always essential. Each piece of equipment should be made-to-order to meet individual patient requirements and must not be expected to do all of the things that a normal extremity can accomplish. Such equipment should not require frequent mechanical overhauling or adjustment. The apparatuses for functional bracing of the arm, which have been used for the purpose of

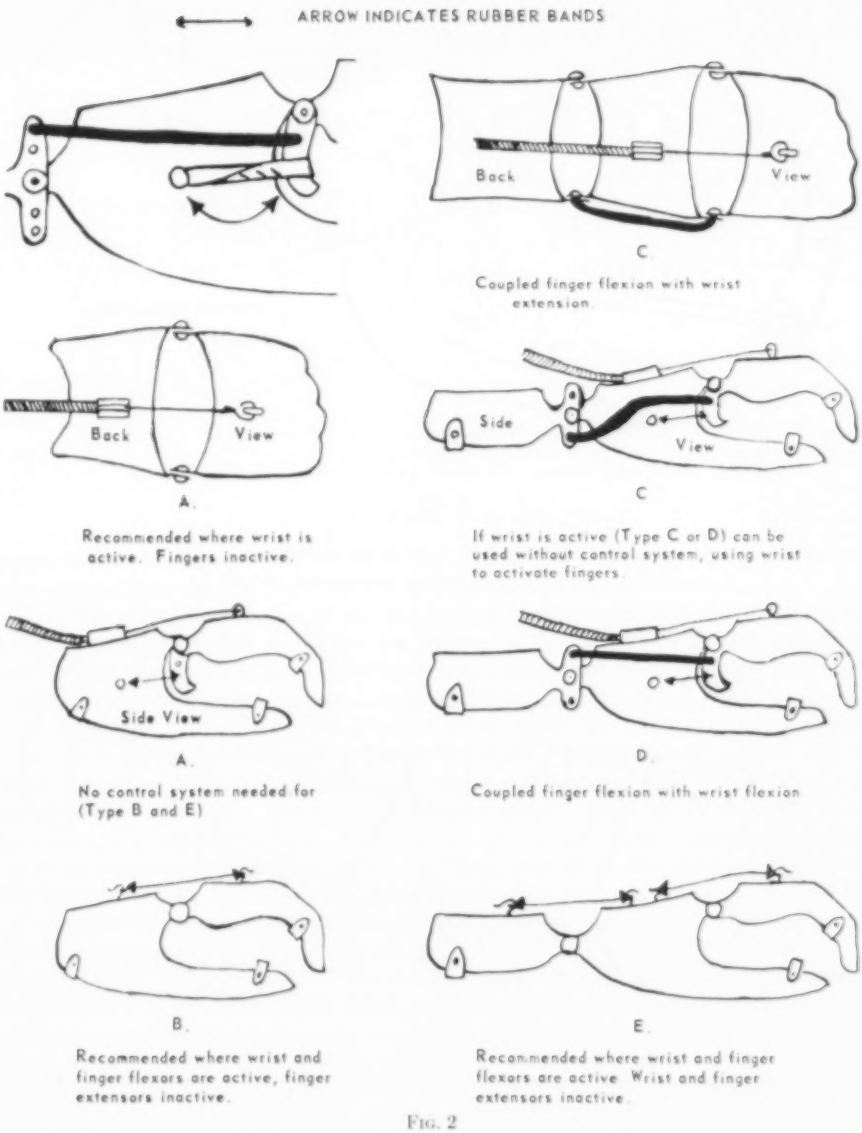

ARROW INDICATES RUBBER BANDS
Back
View
A.
Recommended where wrist is active. Fingers inactive.
Back
View
C.
Coupled finger flexion with wrist extension
Side
View
C
If wrist is active (Type C or D) can be used without control system, using wrist to activate fingers.
Side View
A.
No control system needed for (Type B and E)
D.
Coupled finger flexion with wrist flexion
B.
Recommended where wrist and finger flexors are active, finger extensors inactive.
E.
Recommended where wrist and finger flexors are active. Wrist and finger extensors inactive.

FIG. 2

Variations of the application of the Handy Hand.

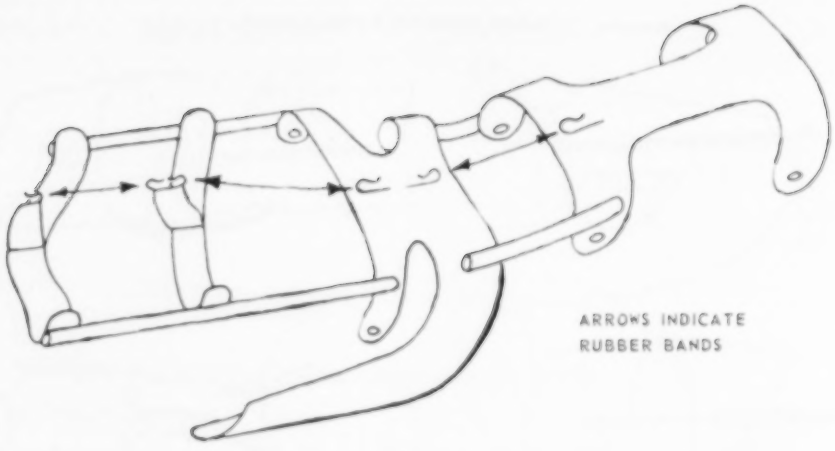
the ensuing study, were designed and developed in their mechanical details by one of the authors, Mr. George Robinson of Robin-Aids. So far as we are aware, they are original. These will be discussed as they refer to the replacement of essential functions as previously outlined.

### GRASP, OR SOME COMPONENT OF GRASP

#### Palmar, Lateral, or Tip Prehension, Cylindrical Grasp, or Hook

1. *The Handy Hand*

The original Handy Hand (Figs. 1 and 2) is a plastic case which encloses the fingers in a shell and the thumb in an opposing shell. It should be so made that the fingers barely




FUNCTIONAL HAND BRACE WITH
FINGER AND WRIST EXTENSION ASSISTS
AND STATIONARY THUMB OPPONENS SPLINT

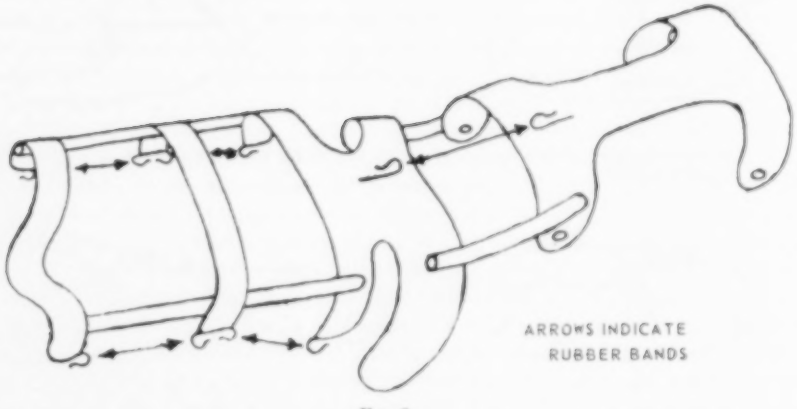



FIG. 3

Hand brace for finger flexion and wrist extension. The stainless steel from which the brace is made is covered with plastisol.

touch and that the increased pressure comes against the finger-and-thumb plastic when the hand is closed in order to prevent continuous pressure of the rubber bands on the soft finger pads. Pressure on the finger pads may be minimized by means of a dorsal cheek strap. The tension of the rubber band enables the thumb to be thrust against the fingers. The Handy Hand may be operated by the other hand when it is to be used as an occasional holding aid, as in peeling potatoes or using a can opener. The hand may be opened by the normally active finger extensors of the affected hand or by means of a cable attached to a shoulder harness. For use in other conditions, the hand may be so constructed that it can be opened by rubber bands and closed by a cable from a shoulder harness. This type of Handy Hand has certain drawbacks, since thumb movement is limited and since the hand is held in a relatively fixed position. However, it does allow touch at the time of

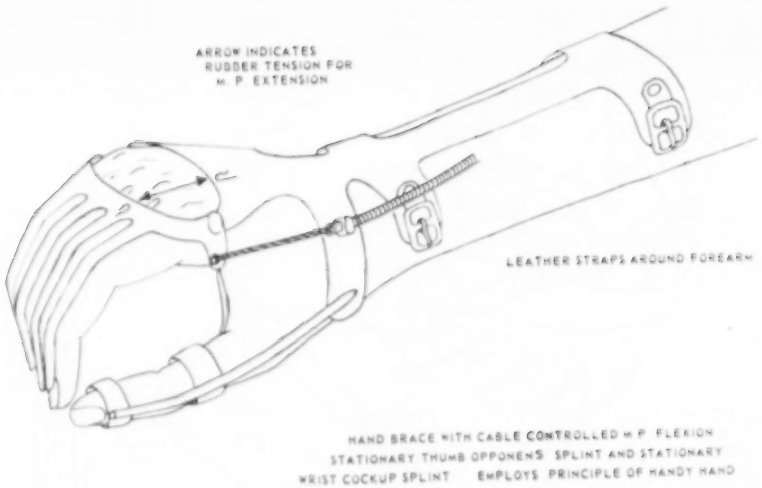

ARROW INDICATES
RUBBER TENSION FOR
M. P. EXTENSION
LEATHER STRAPS AROUND FOREARM
HAND BRACE WITH CABLE CONTROLLED M P FLEXION
STATIONARY THUMB OPPONENS SPLINT AND STATIONARY
WRIST COCKUP SPLINT EMPLOYS PRINCIPLE OF HANDY HAND

FIG. 4

grasp, which is an important consideration. If the hand is operated by normal finger extensors or by a shoulder harness, it may be a satisfactory replacement.

In the more recent styling of the Handy Hand or the functional hand brace (Fig. 3) a light metal hand splint applied to the dorsum of the hand, hinged with springs, and coated with plastisol has been substituted. Only the skeleton of the hand enclosure is used. This apparatus, when indicated, is more comfortable to wear since it is less confining. Each joint is separated by a light piece of metal across the phalanges, metacarpals, or wrist; each spring is individually adjusted, if desired, by rubber-band tension; and each metal phalangeal band is connected to the next in series by means of a light spring which takes the place of a hinge. This type of hand brace may be made either to open or to close by means of a shoulder harness. Elastic motor power may supply opposing function, if either the extensors or flexors are paralyzed. The apparatus gives a more normal grip than the hard plastic case and allows the sensation of touch.

A useful variation of the hand brace (Fig. 4) is a light metal splint which lies dorsally on the metacarpals with the wrist fixed in dorsiflexion. To this splint, a second piece is attached which is hinged only at the metacarpophalangeal joints. The second piece, or finger piece, is so made that each finger is positioned by an individual finger splint lying on the dorsum; the finger splint may be curved and pre-positioned as desired for that finger. The thumb is held in a fixed position by means of a stationary opponens splint placed on the dorsum. The thumb and fingers are maintained against their corresponding splints by means of a small piece of plastic tubing which is placed over the digit and the brace in order to avoid interference with critical finger sensation. The entire brace is covered with plastisol. This design has the advantage of allowing finger closure for holding without a shift of finger position, since the only joints to move are the metacarpophalangeal joints. This brace may be further varied by an adaptation of the hand enclosure depicted in Figure 2, *C*. The brace is stabilized above the wrist, and a wrist joint is provided in addition to the hinged metacarpophalangeal section. No external cable control is needed to activate this hand brace, if wrist extensors are present. Because of the coupled action indicated in Figure 2, *C*, wrist extension closes the fingers. The coupled action is identical to that obtained by wrist extension when there has been a tenodesis of the flexor tendons of the fingers. This brace can also be coupled to produce finger closure by wrist flexion (Fig. 2, *D*).

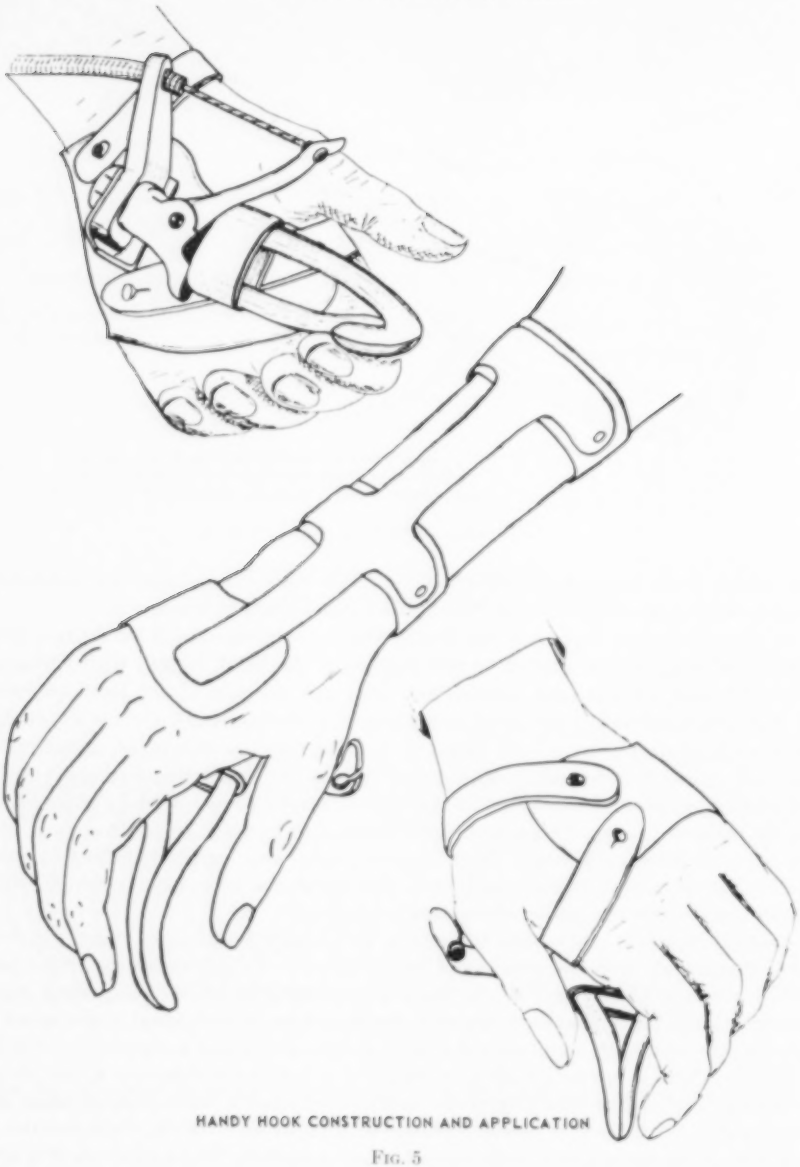



FIG. 5

2. *The Handy Hook*

This may be any standard hook (Fig. 5); our present choice however, is one of the variations of the Dorrance hook. The hook is operated by a shoulder harness, by foot control, by a groin-to-shoulder harness, by a chest strap, by nudge control, or by some other system of remote control. It should be made clear that the recommended system of remote control is a twisted stainless-steel cable running through a spring-wound tubular housing. The hook does not allow the sensation of touch, but is truly a more practical replacement for the flail hand if the patient can be prevailed upon to wear it. The hook will enable the patient to accomplish anything that can be done with equal strength by

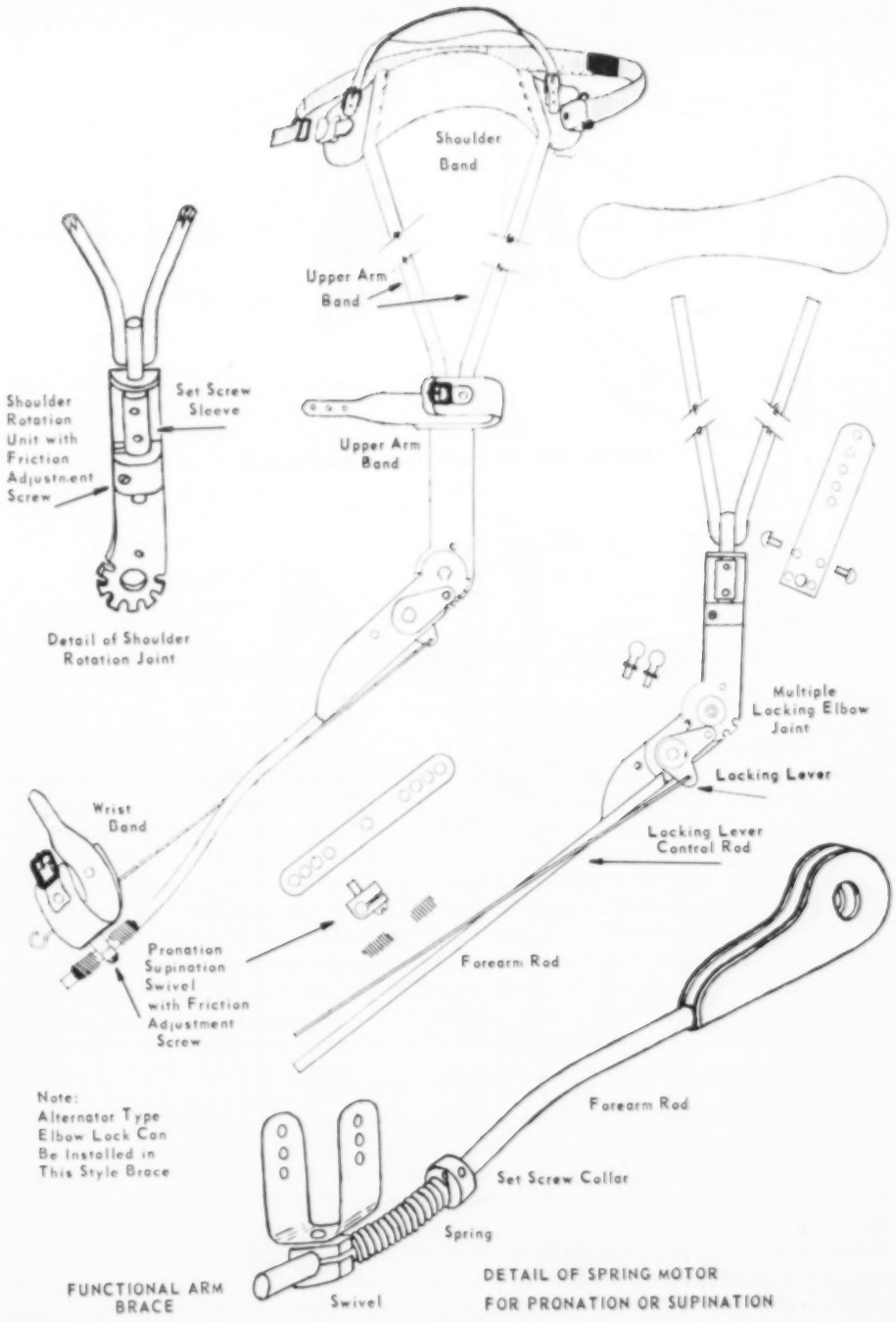
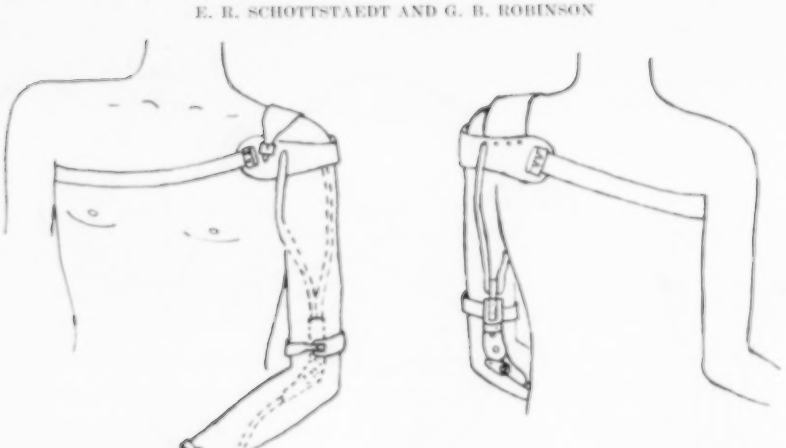

Shoulder Band
Upper Arm Band
Upper Arm Band
Set Screw Sleeve
Shoulder Rotation Unit with Friction Adjustment Screw
Detail of Shoulder Rotation Joint
Multiple Locking Elbow Joint
Locking Lever
Locking Lever Control Rod
Wrist Band
Pronation Supination Swivel with Friction Adjustment Screw
Forearm Rod
Note: Alternator Type Elbow Lock Can Be Installed in This Style Brace
Forearm Rod
Set Screw Collar
Spring
Swivel
FUNCTIONAL ARM BRACE
DETAIL OF SPRING MOTOR FOR PRONATION OR SUPINATION

FIG. 6



APPLICATION OF FUNCTIONAL ARM BRACE

FIG. 7

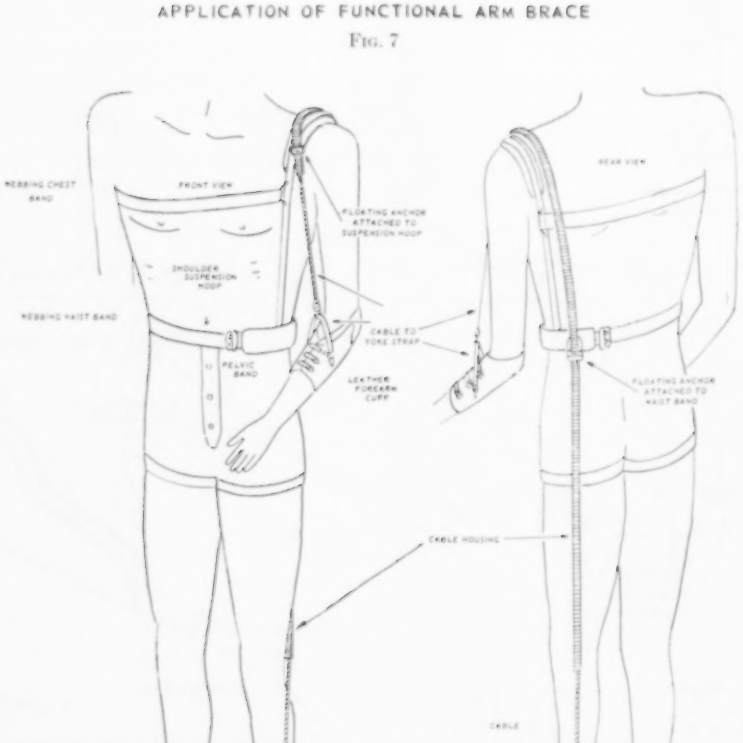



FIG. 8-A

A flail elbow is supplied with motion by the use of a reciprocator from the leg with bail control over the dorsum of the foot (Fig. 8-B).

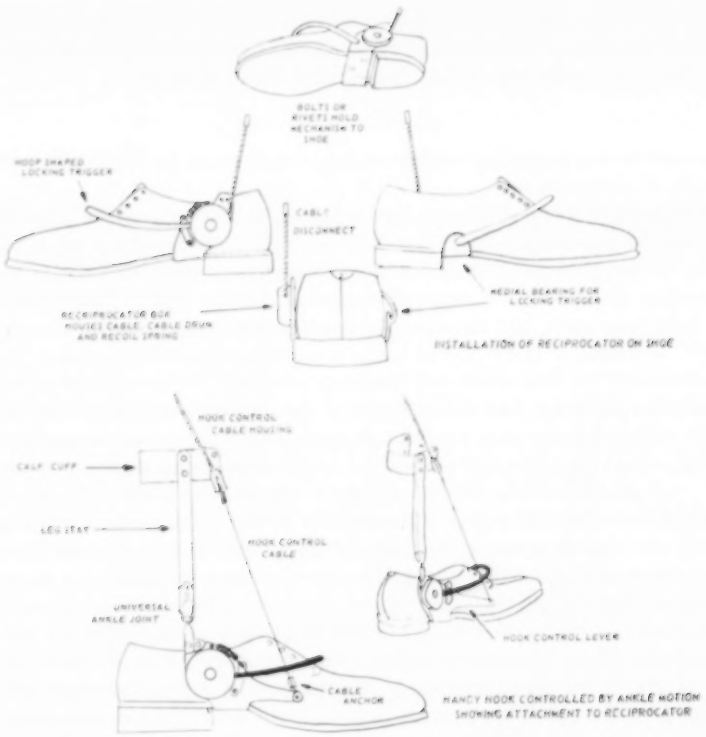

BOLTS OR RIVETS HOLD MECHANISM TO SHOE
HOOP SHAPED LOCKING TRIGGER
CABLE DISCONNECT
MEDIAL BEARING FOR LOCKING TRIGGER
RECIPROCATOR BOX HOUSES CABLE, CABLE DRUM AND RECOIL SPRING
INSTALLATION OF RECIPROCATOR ON SHOE
HOOK CONTROL CABLE HOUSING
CALF CUFF
LEG STAY
HOOK CONTROL CABLE
UNIVERSAL ANKLE JOINT
HOOK CONTROL LEVER
CABLE ANCHOR
NANCY HOOK CONTROLLED BY ANKLE MOTION SHOWING ATTACHMENT TO RECIPROCATOR

FIG. 8-B

an amputee with an arm prosthesis. In the presence of extreme weakness, this may be very light activity. However, if the hand only is flail and the rest of the arm is good, the hook should, if properly attached, allow for all heavy-duty service for which a hook is normally useful. The hook at present is fixed to a metal hand brace or splint, or hand-and-wrist splint. It is not positioned by means of an artificial-arm wrist unit, but by means of normal forearm pronation-supination or by means of a manually operated friction joint in the arm brace. The position of the hook can be altered by changing its position on the hand brace with a screwdriver. The hook is so set that the fingers of the hook lie between the thumb and index finger of the patient's hand. The flange across the metacarpals is best locked to a stable band placed above the wrist in order to immobilize the wrist in some dorsiflexion, unless, of course, there is normal wrist function.

### PRONATION AND SUPINATION

Pronation and supination may be secured by means of a metal rod, usually placed below the ulna from the wrist and hand unit and spiraled around the medial side of the forearm to the elbow unit of the arm brace (Figs. 6 and 7). It is manually pre-positioned, as is the usual friction disconnect unit of an artificial arm, but it may be tightened or loosened by adjusting the tension in the friction joint with a screwdriver. If either good pronation or supination is present, absent power may be supplied by a spring set to oppose the patient-controlled motion. Since pronation and supination must arise from some fixed point, a stable elbow reaction point is necessary. This will usually be a hinged brace, although it need not be if the upper arm and the elbow are satisfactory.

In light-duty equipment, in contradistinction to the fixed type of brace previously

discussed, the elbow is suspended by elastic motors. Here pronation and supination may be supplied by the proper placement of the supporting straps of the elbow cuff. This will be further described under the section dealing with elbow motion.

### ELBOW MOTION

Elbow motion is supplied by various means and can only be discussed clearly by the establishment of circumstances:

*A flail elbow is to be supplied with motion by the use of a reciprocator from the leg with bail control over the dorsum of the foot* (Figs. 8-A and 8-B). A framework must be established on the body for two purposes: (1) to act as a foundation for the cable housing and the reactor points and (2) to act as a point of suspension for the elbow. Various body braces and cages have been used, but the most successful is the hoop attached to a split pelvic band, unless, of course, a body cast or brace is necessary for other reasons. The padded pelvic band rests on the iliac crests and the hoop conforms to the contours of the body as it passes over the shoulder. The anterior arm of the stainless-steel hoop rises in line with the anterior axillary fold to pass over the shoulder above the acromion and to fall along the posterior axillary fold. The cable, anchored to the pelvic band, passes over the shoulder posteriorly, enough slack being allowed so that it cannot bind if the body is inclined forward. The cable is attached to the anterior arm of the stainless-steel hoop at a point directly over the pivotal point, or fulcrum, of elbow flexion. Usually, the pivotal point will lie just distal to the radial tubercle. The elbow itself is secured by a buckled elbow cuff so designed that the region overlying the olecranon will not fall out posteriorly. The cable is attached to a thong connecting the cuff suspension points which are placed medially and laterally. These suspension points will vary, moving toward the wrist with the increasing weight of the hand apparatus. Pronation and supination may be controlled by the placing of the elbow suspension loop to favor either one or the other position. Elbow motion is gained under these circumstances by either hip or knee flexion or extension. (Gravity will supply elbow extension associated with knee or hip flexion through the release of the reciprocator. Flexion is gained by hip or knee extension against a fixed cable length, the proper length having been previously chosen by the patient using the foot control release of the reciprocator.)

*Elbow suspension to supplement weak elbow flexors* (Fig. 9). In those patients with elbow flexors of insufficient power to lift the forearm and hand against gravity, lifting motion can be greatly facilitated by the use of the split pelvic band and steel-hoop assembly. The elbow is suspended from the anterior arm of the steel hoop as it passes in front of the axilla at shoulder level. The pelvic band worn over or above the iliac crests, is the base for the steel hoop. The stable reaction point for elbow flexion on the steel hoop is connected with rubber bands from the anterior aspect of the axilla in front of the bicipital groove to a leather elbow cuff which is buckled to the forearm. Since some elbow flexion may be present, the rubber bands are used to nullify the weight of the arm. Gravity brings the arm back to the starting position, which will usually be 90 to 100 degrees of elbow flexion.

*Hinged elbow joint with a manual locking device to be operated by the opposite hand* (Fig. 6). A simple hinged joint is secured to the upper arm and to the forearm. The center portion of the hinged joint is notched and is made to catch against a hand-operated locking bar. The control for the joint lock is usually placed near the wrist so that it can easily be operated by the patient's good hand. Seven positions of elbow flexion are available. If the patient has some elbow flexion, a large portion of the weight of the forearm may be borne by partial rubber-band suspension, facilitating the shift of elbow position, especially during light activity when the lock may not be necessary.

*Hinged elbow joint with an outside elbow lock operated by the shoulder.* This is a similar elbow brace to that just described except that the elbow lock is operated by means of a

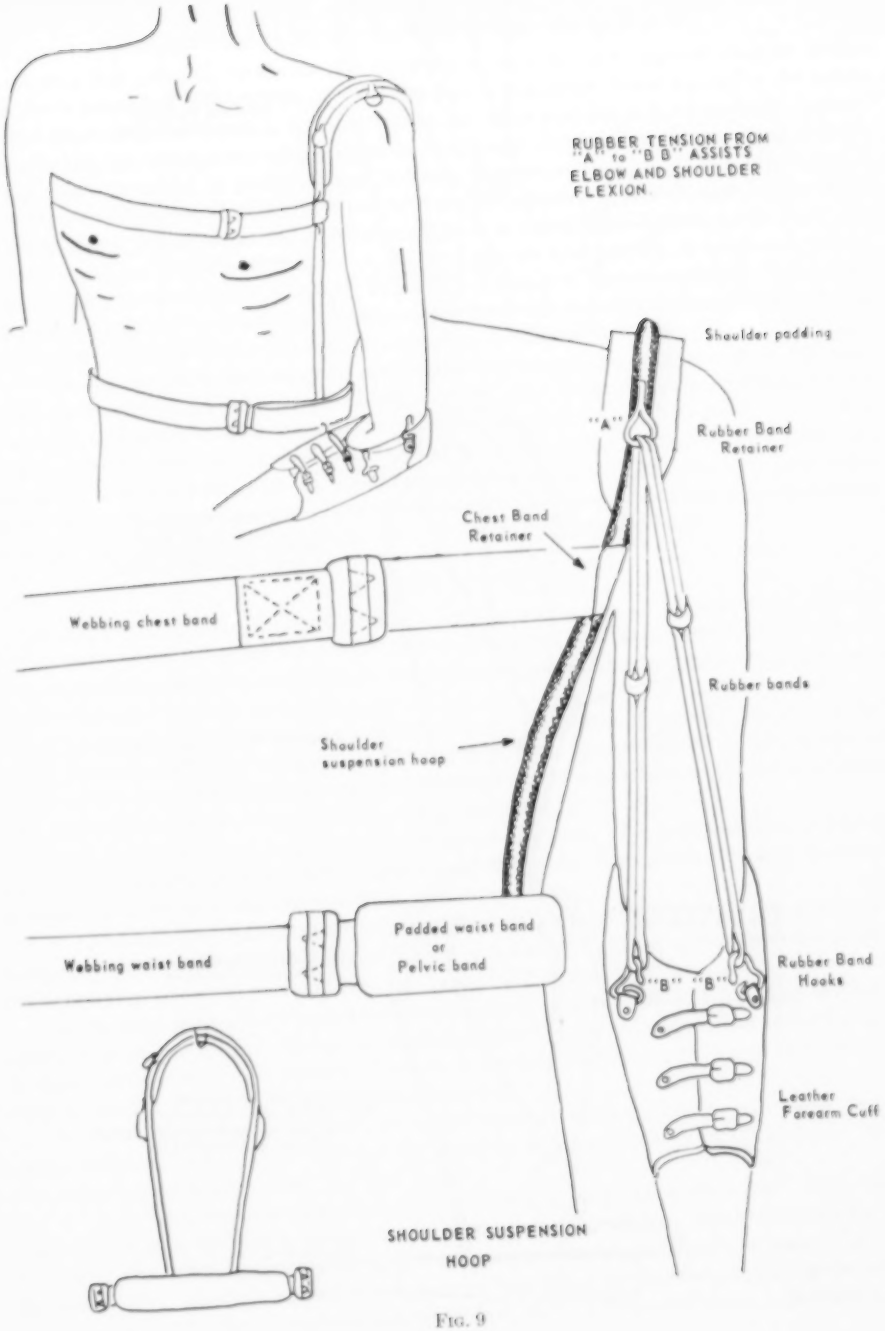
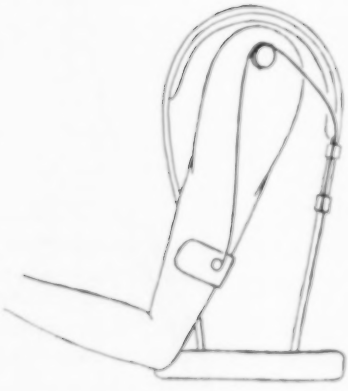

RUBBER TENSION FROM "A" to "B B" ASSISTS ELBOW AND SHOULDER FLEXION
Shoulder padding
"A"
Rubber Band Retainer
Chest Band Retainer
Webbing chest band
Rubber bands
Shoulder suspension hoop
Webbing waist band
Padded waist band or Pelvic band
"B" "B"
Rubber Band Hooks
Leather Forearm Cuff
SHOULDER SUSPENSION HOOP

FIG. 9

ARROWS INDICATE RUBBER BANDS

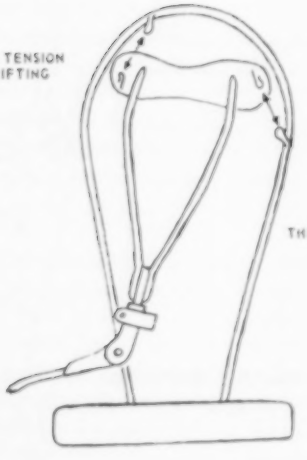
RUBBER TENSION SUPPLIES FORWARD SHOULDER FLEXION

EXAMPLE "A"



COIL SPRING WITH ENDS ATTACHING TO ARM CUFF AND TO SUSPENSION HOOP SUPPLY SHOULDER FLEXION

EXAMPLE "B"



THIS RUBBER TENSION SUPPLIES A LIFTING PRESSURE

THIS RUBBER TENSION SUPPLIES A DOWNWARD PRESSURE

THE COMBINATION OF THE TWO SUPPLY FORWARD SHOULDER FLEXION AND SUSPEND THE WEIGHT OF THE ARM AND BRACE

EXAMPLE "C"

SHOULDER FLEXION ASSISTS

FIG. 10

shoulder harness. The elbow lock is the outside alternator elbow lock designed for use with elbow-disarticulation prostheses.

### INTERNAL AND EXTERNAL ROTATION OF THE SHOULDER

*With a flail extremity by the use of a reciprocator.* Internal and external rotation of the shoulder is provided, although poorly, by suspending the elbow cables medial to the exact pivotal elbow suspension point. In other words, the cable position is fixed medially (nearer the axilla) on the anterior arm of the stainless-steel hoop. This makes the arm swing inward as the elbow is raised in flexion. Since there is no positive control, this is not entirely satisfactory. However, if either internal or external rotation of the shoulder is present, however slight, the arm can be positioned so that it automatically falls away from the motor. Thus, the motor moves the arm in one direction and gravity or an elastic motor brings it back to the opposite position. This is not difficult to harness properly. Activation is best accomplished by leading an elastic motor from any point near the pivotal point of the shoulder, either posteriorly over the acromion, or anteriorly.

*With one good arm and one flail arm when elbow suspension from a hoop is not used.* A closely fitted shoulder band and saddle may be used, from which rods descend both anteriorly and posteriorly to become a single rod passing to the elbow joint. This rod is equipped with a friction joint similar to that used in friction control of pronation and supination and is adjusted in the same manner. Braces of this sort are best used when there is active shoulder shrug to support brace weight. If there is complete scapulothoracic paralysis, the brace may be suspended on a pelvis-based shoulder hoop.

### SHOULDER FLEXION

If backward flexion of the shoulder is possible, as much as 20 degrees of forward flexion may be obtained by an elastic motor. However, for most tasks 5 to 10 degrees of forward flexion is all that is essential. At present, this motion is supplied in one of several ways.

A. A metal arm is mounted on a circular hinge. The distal end of the arm is attached to the humeral cuff. The proximal end of the arm extends beyond the hinge; to this an elastic motor may be attached to regulate the degree of forward flexion. The circular hinge may be varied to allow some abduction. (Fig. 10, *Example "A"*).

B. A cuff is attached to a specially constructed spring. The spring tension is adjustable by varying the tension upon an inner core and cable. The spring assembly in turn is attached on a swivel to the shoulder hoop posteriorly.

C. A simple coil spring with ends attached to the arm cuff and to the suspension hoop may be used to supply shoulder flexion, the strength of the spring depending upon the remaining power of backward flexion (Fig. 10, *Example "B"*).

D. If there is no active backward flexion, the shoulder is pre-positioned by means of either style of cuff at 5 to 10 degrees so that it lies slightly anterior to the coronal plane. If slight forward flexion is present, the arm is brought further forward and is allowed to drop backward. This supplements existing power.

E. With the reciprocator used for elbow flexion, shoulder flexion will occur as the elbow is flexed. As the elbow is flexed the shoulder slides posteriorly in the shoulder hoop and some flexion occurs (Figs. 8-A and 8-B).

F. If an arm brace is suspended from a shoulder hoop, as is often done when there is a flail shoulder, the elastic motor, used for brace suspension, may supply forward flexion by lifting the brace anteriorly toward the anterior arm of the shoulder hoop (Fig. 10, *Example "C"*). Another elastic motor secures the brace by downward pull posteriorly.

In addition to the equipment just described, there are several other important considerations in useful brace prescription.

The reciprocator is sufficiently important to warrant a few additional words regarding

its use and application. This mechanism is used to supply elbow flexion; it transfers hip and knee motion into elbow motion. To be effective, the reciprocator works from a fixed point on the shoe. It allows cable lengthening or shortening by tripping a control much in the same manner as a window shade rolls up or down when a control is tripped. Cable length is adjustable for different positions, and free cable is provided so that no elbow motion will result from normal walking motions. Effective cable shortening, after proper cable length has been obtained by the patient, occurs between the shoe and a point on the pelvic band. The cable is led from the pelvic band to the anterior arm of the steel hoop, directly over the pivotal point, or fulcrum, of the elbow. Here the cable is attached to the cuff yoke strap of the forearm. By use of the adjusted cable, hip or knee extension will provide elbow flexion while gravity provides elbow extension. If a hook is to be operated from the shoe, a short brace with a universal joint which allows all foot motions, is attached to the shoe. Plantar flexion, working against a fixed cable length from the shoe lever to the calf band, provides motion to open the hook. A second cable is used from the hook to the shoe in addition to that used from the reciprocator to the elbow. This cable and housing are fixed at the pelvic band and shoulder to prevent it from wandering. It should be noted that the top of the hoop is padded and is used as the shoulder depressor point with the reciprocator, if there are no shoulder depressor muscles present.

When elbow flexion results from the supplementation of existing elbow flexor muscles and when no shoulder depressor force is present, either shoulder depressor straps or padded shoulder hoops will prevent scapulothoracic elevation and will thus allow elbow flexion and prevent undue excursion of the upper extremity as a whole. The fixation should not be rigid in either instance. When shoulder depressor straps are used, these should be fixed to the anterior and posterior arms of the steel shoulder hoop with rubber-band tension. The depressor strap, when used, is placed so that it lies in the sulcus between the insertion of the trapezius and the origin of the deltoid. This point easily accepts pressure. If these straps are rigidly fixed, the patient cannot lean forward or move easily from side to side, and they will interfere with motion of the shoulder as well as that of the entire thorax.

### HARNESSING

There are four major scapulothoracic movements that can be harnessed. They are scapular elevation (upward shrug, accomplished chiefly by the trapezius and the levator anguli scapulae assisted by the rhomboids), scapular forward flexion (protrusion or forward shrug, chiefly accomplished by the serratus anterior, assisted somewhat by the pectoralis minor), scapular depression (accomplished chiefly by the lattissmus dorsi and the pectoralis major), and scapular retraction (accomplished chiefly by the rhomboids and the lower and middle trapezius). Scapular elevation, forward flexion, and depression are of chief interest to us, although occasionally an opportunity may arise to put scapular retraction to use.

Movements should be harnessed by pulls from fixation points exactly opposite the greatest range of motion. Adequate motor power, however, does not depend upon shoulder motion alone, but may be obtained in many different ways, depending upon the remaining motors. Several harnessing possibilities will be briefly outlined:

A. Elbow flexion may be accomplished by hip and knee extension and aided by a reciprocator or some similar device (Figs. 8-A and 8-B).

B. Opening of a hook or hand may be accomplished by harnessing plantar flexion of the foot (Figs. 8-A and 8-B).

C. Hook opening can be accomplished by harnessing neck rotators and flexors.

D. Scapulothoracic elevation may be harnessed by attaching a groin strap from either lower extremity to a mobile shoulder strap to act as a reaction point. The split pelvic band lying on the iliac crest may serve as the point of fixation in place of the groin strap when the pelvic band is necessary as a base for elbow-flexion apparatus (Fig. 11).

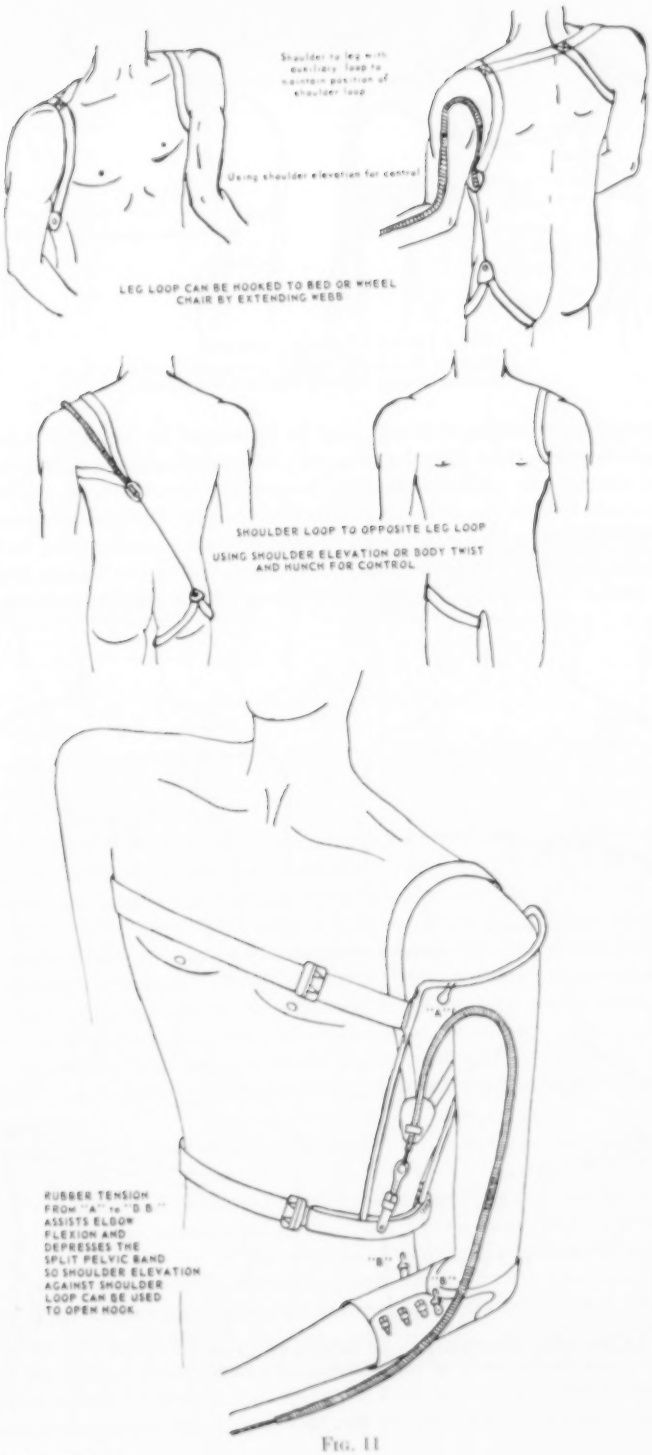

Shoulder to leg with auxiliary loop to maintain position of shoulder loop
Using shoulder elevation for control
LEG LOOP CAN BE HOOKED TO BED OR WHEEL CHAIR BY EXTENDING WEBB
SHOULDER LOOP TO OPPOSITE LEG LOOP
USING SHOULDER ELEVATION OR BODY TWIST AND HUNCH FOR CONTROL
"A"
"B"
RUBBER TENSION FROM "A" to "B" ASSISTS ELBOW FLEXION AND DEPRESSES THE SPLIT PELVIC BAND SO SHOULDER ELEVATION AGAINST SHOULDER LOOP CAN BE USED TO OPEN HOOK

FIG. 11

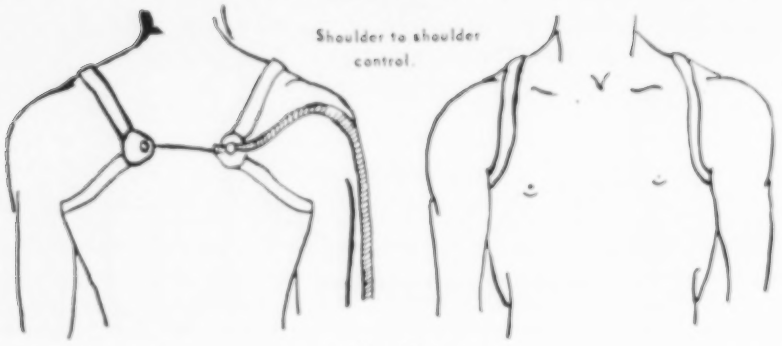



FIG. 12
Scapulothoracic forward flexion is harnessed.

E. Scapulothoracic forward flexion may be harnessed by means of a figure-of-eight axillary loop over the normal shoulder (Fig. 12). Normal scapulothoracic movement may be harnessed against the opposite shoulder from a reaction point on the arm brace or against a retention loop on the shoulder of the involved side. If scapulothoracic movement is normal bilaterally, then either shoulder, or both of them together, may be harnessed to provide suitable excursion. In harnessing for the operation of the Handy Hand, we have successfully used a scapulothoracic forward flexion for one motion and scapulothoracic

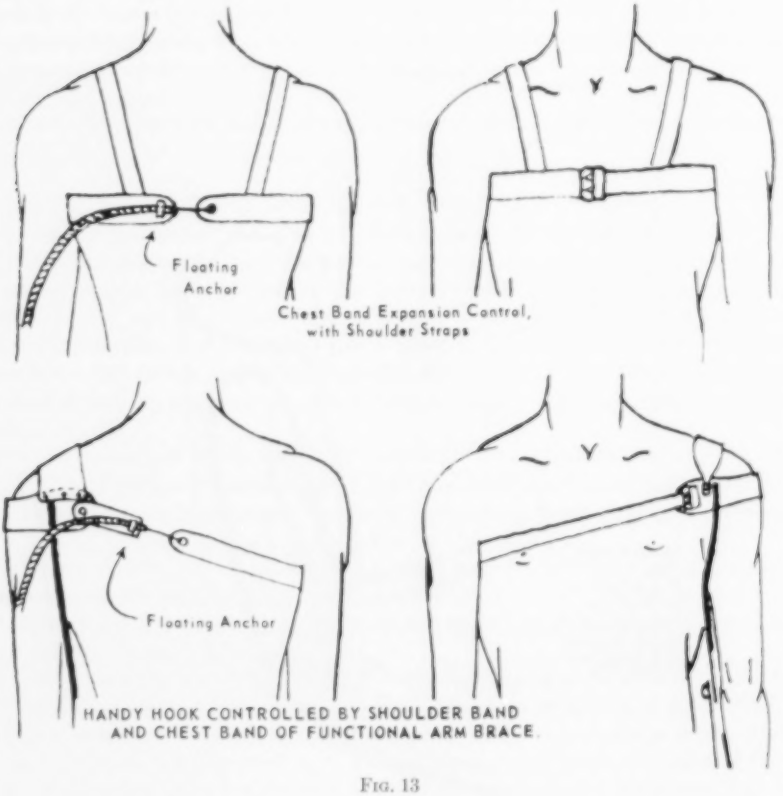



FIG. 13

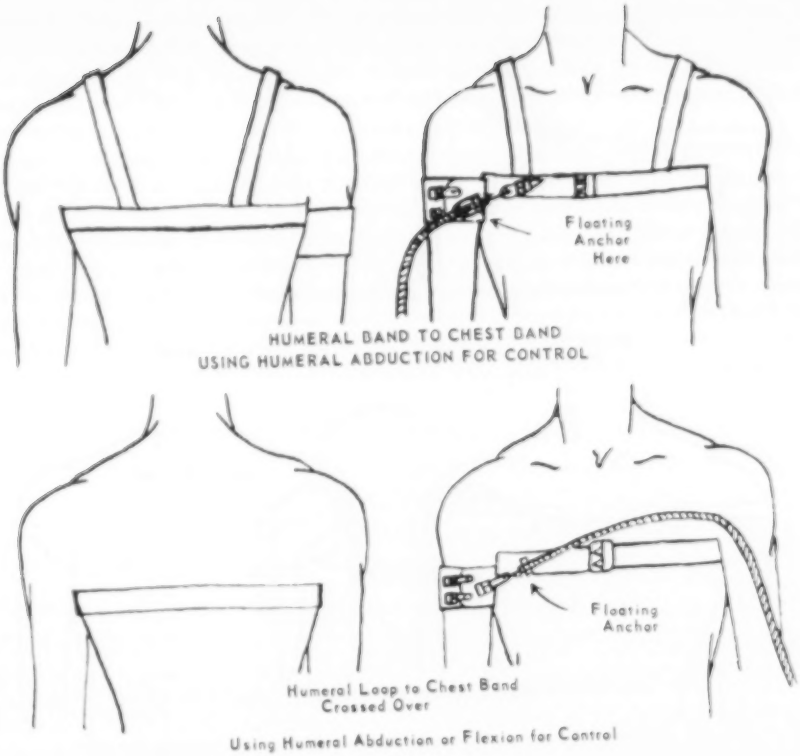



FIG. 14

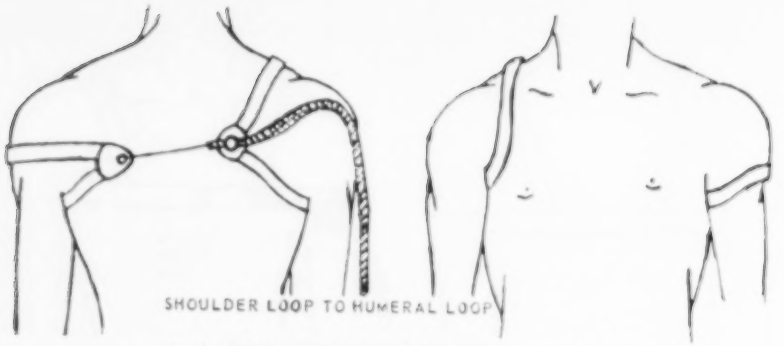
retraction for another. This principle is often used with an above-the-elbow prosthesis. Scapulothoracic forward flexion and depression, harnessed with a chest strap, provides power for opening a hook while scapular retraction activates the elbow lock. In harnessing to provide power for a brace used with a flail hand, the hand brace is adjusted to the bilaterally applied figure-of-eight harness so that the thumb and fingers lie partially open when the shoulder is relaxed. Scapulothoracic forward flexion closes the fingers while scapulothoracic retraction relaxes cable tension and allows the elastic tension of the brace to open the gap between the thumb and the fingers so that larger objects may be grasped. Sometimes, for even greater range, a small additional shoulder strap, lying over the point of the shoulder, is attached to the axillary loop. This takes advantage of all possible scapulothoracic motion.

F. Pectoral expansion, or shoulder depression or both can be harnessed by means of a chest strap (Fig. 13).

G. Humeral abduction or flexion or both can be harnessed by means of a loop around the upper portion of the humerus (Fig. 14). This gives a good range of motion but tends to interfere with the function of the normal extremity. However, it may be necessary occasionally to make use of this harnessing technique.

H. Humeral abduction or flexion and scapulothoracic forward flexion, or both, (Fig. 15) when harnessed, will give an even greater range, but will tend to interfere with function of the normal extremity.

I. A wheel-chair lever placed to operate a hook by means of some other body motion (knee flexion or extension, hip abduction) may be used when the conventional harnessing



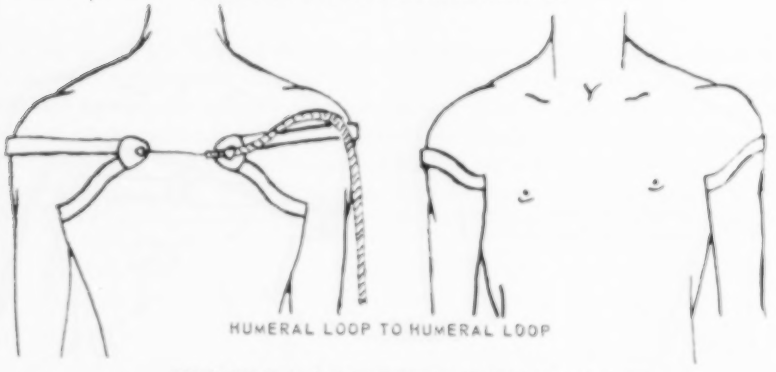




FIG. 15

techniques already described are not applicable. This has the obvious disadvantage of limiting the usefulness of the hook to wheel-chair use (Fig. 16).

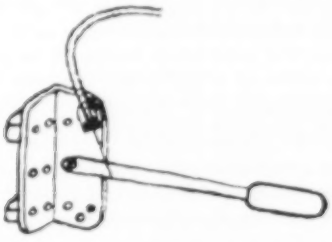
All of the shoulder and pectoral harness techniques described may be used to open a hook. Power from humeral flexion or abduction may be used for elbow flexion. If outside alternator elbow locks are used, the locks may be operated by scapulothoracic retraction, pectoral expansion, backward flexion of the scapulohumeral joint, shoulder elevation, or nudge control.

It should be remembered that shrug of the opposite shoulder, if used, must have a stable or fixed point on a shoulder brace to work against or the weak arm will merely travel backward as the normal scapula is moved forward.

It may be useful to compare briefly the arm prosthesis with the arm brace. The aim of each is obviously the same — to restore useful function to a damaged upper extremity. The general principles are similar. The arm prosthesis provides total replacement of joints and motors, but it cannot provide sense of touch, and there is a marked decrease in proprioceptive perception. The arm brace has a distinct advantage in that sensation and proprioceptive sense are preserved. One fundamental difference between an arm prosthesis and an arm brace is the difference in weight. The standard plastic prosthesis is very light, while the human arm with a brace weighs much more. The additional weight must be compensated for in some manner in order to make the apparatus entirely satisfactory. This is done, as previously noted, but not directly stated, whenever possible by suspending joints with elastic motors from portions of the brace in order to avoid the effect of gravity. In

other words, the joint is suspended. This is most easily seen at the elbow joint where, even with a locking device, the elbow is suspended by elastic motors so that any small amount of remaining motion may be used by the patient without locking the joint. Without this floating suspension, the weight of the arm and apparatus would often be enough to make it impossible for the patient to use the extremity efficiently.

It becomes obvious that a brace only activates an extremity or supplements an existing power. There is another avenue of approach to bracing of the arm not as yet thoroughly explored. This consists of thinking and planning brace use in conjunction with surgical reconstruction. If a motor can be supplied to a hand, as is done by any of the usual wrist to finger muscle-tendon transplantations, with or without arthrodesis, then an elastic or spring motor or a shoulder harness motor may be provided to give opposing function and to improve the functional use of the hand operated upon. If a flail hand can be supplied with finger flexion, active extension may be provided by this means. If there are insufficient remaining motors to provide thumb and finger flexion, the fingers can be



CONTROL LEVER FOR HANDY HOOK FOR WHEEL CHAIR MOUNTING.

Can be operated by chin pressure, shoulder elevation, foot pressure, leg abduction

FIG. 16

brought to an activated thumb. If a thumb is overpulled by an active muscle transplantation from the wrist, a small spring or elastic-motored brace can pull the thumb into extension and improve function, as well as prevent deformity. Such bracing will be found useful, not only as supplementation for partial surgical reconstruction in poliomyelitic paralysis, but also for peripheral-nerve injuries, and in some patients with flaccid hemiplegia and quadriplegia. A weak sternocleidomastoid transplant to provide elbow flexion may be supplemented by elbow suspension bracing and thus provide greater elbow function by the partial elimination of the effects of gravity. In many instances, bracing can be made less cumbersome through the use of surgical techniques first. It is our feeling that surgical reconstruction, wherever possible, is superior to bracing in rehabilitation of the patient with paralysis of the upper extremity.

With the use of functional bracing of the arm, the patient not only has actual improvement in function of the arm as the direct result of better stability and power provided by the brace, but also other benefits, such as a gain in strength of the antagonist muscles and a definite improvement, often, even several years after the onset of poliomyelitis, in the weak assisted muscles. This occurs because, if the elbow flexor or shoulder rotator graded *trace* or *poor minus* attempts to aid in the assisted motion, the muscle is able to work through a greater range. It is also in a working position, and, therefore, although initially only able to make one or two contractions, it gradually is able to make more and more contractions. Although the patient's muscle may tire and the desired motion cannot be done for a time, as the muscle recovers from its fatigue, it joins in the activity. It is already in position and may make another useful contraction. Thus, by constant proper positioning

and assistance, the muscle may join in motion and gradually become stronger. We have never seen contractures develop from the strengthened antagonist muscles in arm bracing, since motions are carried through a wide range of joint motion. The useful range is just opposite the extreme position of the antagonist. As an example, a strengthening triceps, with a poor biceps, works from the flexed position to bring the arm into the extended position but is always stretched in flexion, since flexion is a supported motion. Therefore, the joint does not lie in extension in which contracture might occur.

We were at first disturbed because some of our patients no longer used their arm braces in activities for which they had originally found the braces essential. However, on careful analysis and questioning, we found that this was true because of improved muscle strength. We, therefore, now view our arm braces as successful, if the patient finds them continuously useful or if he outgrows their necessity through improved muscle strength. We also feel that these braces should not be reserved for the patient with long-standing paralysis as the result of poliomyelitis, but that they should be used to hasten the recovery of upper-extremity muscles. Of course, the braces should be used in carefully selected cases —not every upper extremity is a suitable subject.

## SUMMARY

1. The patient must have a source of power which can be harnessed.

2. An analysis of a patient's needs should include special attention to the essential motions to be replaced (grasp, pronation, supination, elbow flexion and extension, internal and external rotation of the shoulder, and shoulder flexion).

3. The brace must be light, comfortable to wear, and, if possible, should be so constructed that the patient can put it on or take it off by himself.

4. The necessary working area for the desired activity should be known and properly planned for.

5. Arm braces at the present stage of their development can replace many normal activities but not all of them. They should be planned to accomplish specific tasks.

6. Arm braces must work from a stable base on the patient's body.

7. Harnessing must supply a satisfactory range of motion and power for the activities desired.

8. A brace must be relatively simple in operation so that its value is worth the patient's effort in making it function.

9. The braces must be simple and sturdy enough so that frequent breakdowns do not occur and frequent adjustments are unnecessary.

Other important factors that should always be considered are:

1. The patient must desire help and must be willing to put up with minor inconveniences in the appliance and its appearance.

2. Careful analysis of the patient's desires and potentials by physician, physical therapist, occupational therapist, and prosthetist before final prescription will assure a better functioning appliance.

3. Proper training in the use of the appliance by a qualified occupational therapist or physical therapist is desirable upon delivery of the brace or apparatus.

4. The prosthetist must be willing to devote time for the final careful adjustment of equipment, for often a change from one-quarter to one-half of an inch in a suspension point will mean success or failure.

5. The manufacturer of functional braces for the arm and the fitter should have a knowledge of upper-extremity function. They should be thoroughly familiar with harnessing of artificial arms and the equipment involved in their use; they should be able to think in terms of motion rather than in terms of statics and positioning.

## CONCLUSION

It is our feeling that functional bracing of the arm should not supersede reconstructive

surgery for the upper extremity. A reconstruction, if properly conceived and executed, is always superior to the use of an external appliance. However, functional bracing of the arm will occasionally serve to supplement surgical results. It will also add tremendously to the function and work efficiency of a large group of patients in whom surgical therapy is either totally impossible or of slight value without such supplementation. Never again should we hear the suggestion that a flail upper extremity be amputated, for it may very well serve as a superstructure for a successful functional brace.

NOTE: We wish to take this opportunity to acknowledge the financial aid given by the National Office of the National Foundation for Infantile Paralysis through the courtesy of Dr. Hart E. Van Riper, and to the local chapters of California, Nevada, Utah and Idaho, which have underwritten many of these braces. A group of these braces was also made possible through the interest and aid of Dr. Frederic C. Bost and the San Francisco Shriners' Hospital. We extend our thanks to the San Francisco Veterans Administration Office and the San Francisco Bureau of Vocational Rehabilitation for their cooperation. Valuable assistance in this study has been given in both prescription and training by Miss Donnamae Winters and Mrs. Evelyn Alexander of the May T. Morrison Center for Rehabilitation, where the major part of this work originated.

## DISCUSSION

DR. C. EDWIN IRWIN, WARM SPRINGS, GEORGIA: I must of necessity confine my remarks to functional bracing of the upper extremity as it pertains to the poliomyelitic patient. I am thoroughly in accord with the use of light-weight dynamic splinting for the patient convalescing from an attack of poliomyelitis. Such splinting is necessary for the support of muscle weaknesses, for the maintenance of the extremity in good alignment, for the preservation of joint motion, and for aid in the prevention of deformity. I want to emphasize again that the splints should be simple in design, light in weight, and easily removed and reapplied for necessary daily treatment.

When the patient's recovery has reached its plateau (this should not necessarily be a period of two years) it is time for the orthopaedist to work with the patient for his rehabilitation into society and into a gainful occupation in a normal every-day environment. This aim should be accomplished with as little assistive and supportive apparatus as possible. The patient should be thoroughly evaluated by the orthopaedist and a possible plan or plans of surgical rehabilitation should be considered in order to rid the patient of as much apparatus as possible. Apparatus for the lower extremities will be tolerated a life time by the patient because the support of a brace or braces may mean that he will or will not walk. Many patients with lower extremity braces will ultimately resign themselves to a wheel-chair existence in order to rid themselves of conspicuous and cumbersome apparatus as a means of locomotion.

Use of the upper extremity, particularly the hand, does not mean that the patient has to accomplish as many and as difficult useful functions in a normal manner. Many of these functions can be accomplished with very little strength and in a different fashion from that which he employed prior to the onset of poliomyelitis. I have learned over the years that patients at this point, rather than being satisfied to continue using functional apparatus, are extremely anxious to discard as much as possible, and often they will of their own accord discard upper-extremity apparatus whether or not we attempt to aid him to this end.

We cannot overlook and fail to appreciate the substitution patterns that persons cultivate, which enable them to do an amazing number of things without surgery or assistive apparatus. Oftentimes, although bracing is done in good faith, we may be interrupting these patterns, disabling the patient rather than assisting him. The authors have stated: "It is apparent to most of us that wrist flexion and extension are not essential movements; these are indeed often by-passed by arthrodesis of the wrist. In bracing of the arm, the flail wrist is usually best stabilized in the most functional position". These are statements with which I cannot agree. I think a flexible wrist joint is quite necessary for the restoration of many functions of the hand that otherwise would be impossible. We must not forget that hand function depends upon flexibility and mobility rather than upon stability. It is surprising how useful wrist motion is in propelling a wheel chair and in moving the hand across flat surfaces by abducting and adducting the wrist and how useful wrist motion is when a patient supports his body weight on the hyperextended palm. For the patient who has an arthrodesed wrist, the door has been closed for a very important surgical procedure that is not given wide-spread publicity in this country: namely, tenodesis of the flexor and extensor tendons.

With tenodesis of the extensor tendons a patient is, of course, dependent on wrist flexion to extend the digits; when the wrist is dropped, the fingers are extended through the extensor slips even without power in the intrinsic muscles. The opposite is true in tenodesis of the flexor tendons. When the forearm is supinated, the wrist drops in hyperextension and the hand will form a very useful hook with some semblance of grasp. As the weight of an object is increased with the forearm in supination, the wrist is forced further into hyperextension and the tenodesis grasp is increased.

I was interested in hearing of some of Dr. Schottstaedt's cases and descriptions of apparatus he had prescribed. It is remarkable the many approaches we have to the care of these patients' needs. I think the mechanical principles of the braces have merit, but I wonder if some of the extensive harnessing will be practical after the patient leaves the hospital or convalescent home to return to a normal environment.

# Non-Suppurative Osteitis Pubis in the Female *

BY LEON L. WILTSE, M.D., LONG BEACH, CALIFORNIA, AND
CHARLES H. FRANTZ, M.D., GRAND RAPIDS, MICHIGAN

Edwin Beer was the first to record in the English literature the condition now referred to as osteitis pubis. During a period of eight years, he had repeatedly observed the occurrence of this condition following suprapubic operations on the bladder, and in 1924 he wrote his original article, describing the symptoms of this "painful complication".

Since 1924, a considerable number of articles on the subject have appeared in medical journals [14]. Most of these articles have been in the urological literature [2, 3, 10, 21], but a number have appeared in *The Journal of Bone and Joint Surgery*, including three in the last ten years [1, 7, 18].

The bony changes which characterize this condition have been described under the terms periostitis, osteochondritis [17], osteomyelitis [24], symphysial osteo-arthropathy, and, more recently, osteitis pubis—the choice of terms depending upon the structures involved, the appearance of the lesion, and the particular observer who was describing the condition.

It is now well established that occasionally, after almost any surgery or traumatic manipulation of the organs adjacent to the pubis and especially after cystotomy or prostatectomy, alterations will appear in the anterior portion of the pelvic girdle. These alterations are of the general nature of low-grade osteoperiostitis with resorptive bone changes, and they are usually limited to the pubic bones and ischia, although the acetabulum may also be involved. A very definite roentgenographic picture and symptom complex have been observed. This condition has been considered to be a disease of the male, since by far the greatest number of cases have occurred following prostatic surgery. Among three hundred male patients upon whom suprapubic operations had been performed, Kirz reported an incidence of 3 per cent, and the incidence among patients upon whom retropubic operations have been performed is said to be even higher.

In this article the authors wish to report the occurrence in thirteen women of a disease which they believe is a definite clinical entity related to, but not identical with, the condition osteitis pubis which is seen so frequently in men. The disease seen in the thirteen women was non-suppurative and non-inflammatory and developed in the anterior portion of the pelvic girdle. In five of the women, the symptoms were first noted during pregnancy; in five others, the symptoms appeared within two months after delivery; in one, they appeared after extensive pelvic surgery; and in two they developed after an injury.

The typical female patient with this disease (usually a young woman) begins to experience pain about the symphysis within a few months after the occurrence of some event capable of producing trauma in the adjacent structures. A physical examination reveals tenderness directly over the symphysis, although no swelling or fluctuation is seen. Blood and urine studies give normal results, and fever is absent or low grade. Frequently, there is instability at the symphysis, as can be demonstrated by x-ray, and the opposing sides of this structure will slip up and down as much as one-fourth of an inch when the patient steps from one foot to the other. The pain often becomes so severe that she is completely bedridden and can neither sit nor stand. The roentgenograms made at the onset of symptoms will usually show only negative results, but later, as the disease progresses, they will show spotty demineralization of the bone adjacent to the symphysis, widening of the symphysial gap, and finally gradual development of sclerosis and narrowing. These changes never extend more than a few centimeters laterally from the symphysis

* Read at the Annual Meeting of the Western Orthopedic Association, San Francisco, California, October 14, 1954.

FIG. 1-A

Case 1 (Table I). An anteroposterior view (September 12, 1950) of the pelvis, made seven months after the onset of symptoms. On the opposing surfaces of the symphysis there is an area of spotty destruction, and beyond this area sclerosis of the bone is apparent. The diseased area extends about two and one-half centimeters on either side of the symphysis, and the symphysis itself is definitely widened.

and are nearly always symmetrical. The disease is self-limited; and gradual symptomatic recovery occurs, this recovery taking from a few weeks to three and one-half years.

## CASE REPORTS

Table I lists the salient points of all of the authors' thirteen cases. Roentgenograms for Cases 1, 2, 5, 7, 9, 10, and 11 are presented, as well as photomicrographs of biopsied material for Case 1.

In order that the entire picture may be better presented, four cases from Table I will be given in detail. Each of these cases represents one of the four groups into which the thirteen cases have been divided, this grouping having been made on the basis of the various factors which precipitated the disease.

CASE 4: Onset of symptoms during pregnancy. A white female, twenty-two years old, was seen in the sixth month of her second pregnancy. She complained of severe pain in the pubis and in the anterior portion of the pelvis and was unable to abduct the thighs. The pain increased in severity until by the last two months of pregnancy she was confined to bed. Following delivery, however, a gradual subsidence of the pain occurred, and three weeks after delivery she was feeling quite well. She has had no pain during the last four months and was symptom-free at the time of writing.

At no time was there swelling or abscess formation. Treatment was symptomatic, that is, by bed rest, warm packs, and analgesics. A roentgenogram of the pelvis, made a few days after the onset of trouble, showed marked widening of the symphysis with roughening of the pubic borders. There was also spotty demineralization next to the symphysis, but no sclerosis was apparent. This woman had a definite emotional problem in addition to her physical trouble.

CASE 11: Onset of symptoms shortly after delivery. A white female, aged twenty-nine, had an onset of symptoms a few days after delivery. These symptoms consisted of excruciating pain in the pubis and inability to walk because of pain in the right adductors; an examination revealed marked loss of abduction and marked spasm of the right adductors.

In this case, a roentgenogram made for pelvimetry two weeks before the onset of symptoms was available (Fig. 7-A). This roentgenogram showed no evidence of disease, and the only change that it showed was a slight widening about the symphysis. A roentgenogram made six weeks after the onset of trouble (Fig. 7-B) demonstrated widening and roughening of the symphysis and also revealed an area of destruction on the inferior surface of the right pubic bone near the symphysis.

TABLE I

THIRTEEN NEW CASES

| Case No. | Age at Onset | Mode of Onset | Initial Symptoms | Fever | Urinalysis and Blood Studies | Fluctuation, Abscess, Drainage, Sequestration | Instability at Symphysis Demonstrated |
|---|---|---|---|---|---|---|---|
| 1 | 34 | Two months post partum | Deep pain in pubis, inability to abduct thighs, marked tenderness over pubis. | None | Normal | None | Yes (Figs. 1-A and 1-D) |
| 2 | 31 | Two months post partum | Pain in symphysis and deep pain in pelvis with tenderness over pubis. | None | Normal | None | Yes (Figs. 2-C and 2-D) |
| 3 | 30 | Three weeks post partum | Pain and tenderness in pubis. | None | Normal | None | Not checked |
| 4 | 22 | Sixth month of pregnancy | Severe pain in pubis, tenderness over symphysis, inability to walk lasting two months. | None | Normal | None | Not checked |
| 5 | 28 | Sixth month of pregnancy | Pain so severe could not walk, confined to bed for a month. | None | Normal | None | Yes (Figs. 3-C and 3-D) |
| 6 | 27 | Fifth month of pregnancy | Pain and tenderness in pubis so severe she was confined to bed for five weeks. | None | Not recorded | None | Not checked |
| 7 | 30 | Third month of pregnancy | Pain in pubis so severe she was semi-invalid for seven months. | None | Not recorded | None | Not checked |
| 8 | 39 | Two months after pelvic surgery | Pain in pubis and tenderness, but never incapacitated. | None | Normal | None | Not checked |
| 9 | 49 | Following injury sustained while playing badminton | Pain and tenderness severe, but could still get about. | None | Not recorded | None | Not checked |
| 10 | 37 | One month after auto accident | Pain and tenderness in symphysis, severe adductor spasm. | None | Not recorded | None | Not checked |
| 11 | 29 | Few days post partum | Excruciating pain and tenderness in pubis. | None | Normal | None | Not checked |
| 12 | 40 | Seventh month of pregnancy | Severe pain in pubis, adductor spasm, confined to bed. | None | Normal | None | Not checked |
| 13 | 23 | Twenty-four hours post partum | Severe pain in pubis, not confined to bed. | None | Not recorded | None | Not checked |

TABLE I

THIRTEEN NEW CASES

| Biopsy | Treatment | Changes at Symphysis Seen on Roentgenograms | Total Duration of Pain | Follow-up Time | Status When Last Seen |
|---|---|---|---|---|---|
| Yes (Figs. 1-B and 1-C) | Symptomatic: sedation, warm packs, corset, physical therapy, bed rest | Spotty destruction at symphysis, later sclerosis. (Figs. 1-A, 1-D and 1-E) | Two years | Two and one-half years | Well except for tenderness at symphysis. |
| No | Symptomatic | Spotty demineralization at symphysis. (Figs. 2-A through 2-E) | Two years | Three and one-half years | Well |
| No | Symptomatic | Mottled rarefaction, widening and roughening. | One year | One and one-fourth years | Well |
| No | Symptomatic | Widening and roughening with spotty demineralization. | Four months | Six months | Well |
| No | Symptomatic | Early spotty demineralization and later sclerosis. (Figs. 3-A through 3-D) | | Two years | Still disabled |
| No | Symptomatic | Narrowing and roughing with sclerosis. | Three years | Three years | Well |
| No | Symptomatic | Roughening, spotty demineralization and later sclerosis. (Figs. 4-A and 4-B) | Three and one-half years | Three and one-half years | Nearly well |
| No | Symptomatic | Considerable narrowing, roughening, and spotty demineralization. | Two years | Three years | Well |
| No | Symptomatic | Bony condensation. (Figs. 5-A and 5-B) | Four and one-half years | Five years | Well |
| No | Sedation, corset, physical therapy, x-ray therapy, ACTH, cortisone, phenylbutazone | Narrowing and sclerosis. (Fig. 6) | Eight months | Thirteen months | Well |
| No | Symptomatic | Roughening and widening, area of destruction. (Figs. 7-A and 7-B) | Three months | Four months | Well |
| No | Symptomatic | Mild increase in sclerosis. | Three and one-half months | One year | Well |
| No | Symptomatic | Spotty demineralization. | | One year | Still having slight pain. |

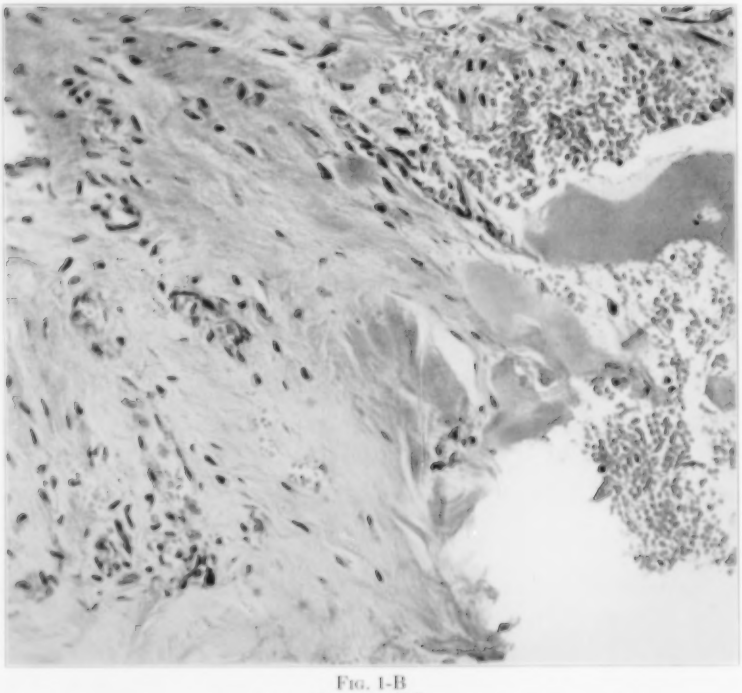


FIG. 1-B
(see page 505)

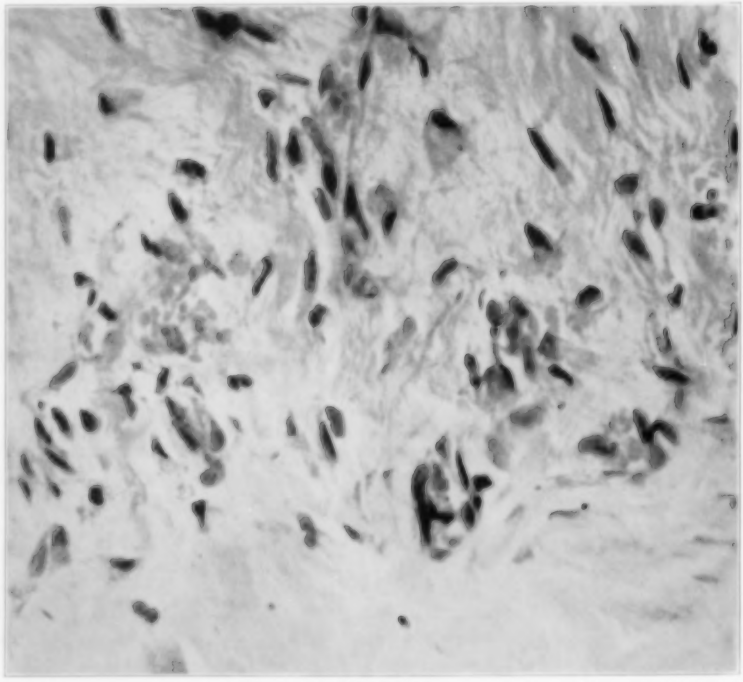


FIG. 1-C
(see page 505)

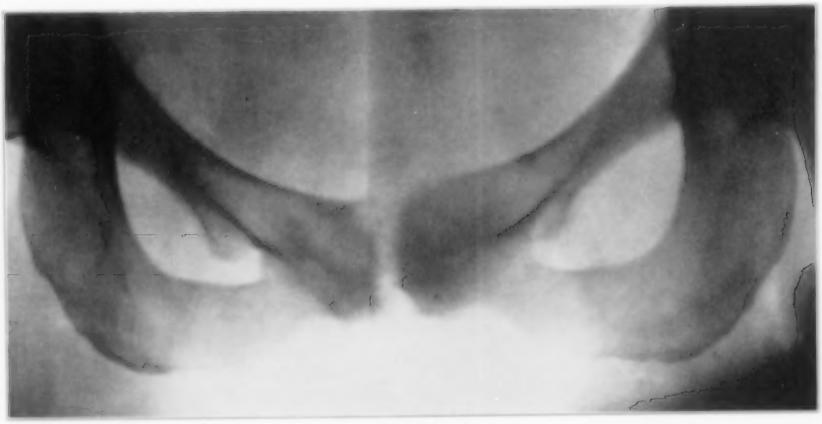


FIG. 1-D

Anteroposterior view (September 12, 1950), of the pelvis, made when the patient was standing with her weight on the *left foot*. A comparison of this view with the view shown in Fig. 1-A, which was made when the patient was supine, reveals that there is a mobility at the symphysis of one-eighth of an inch.

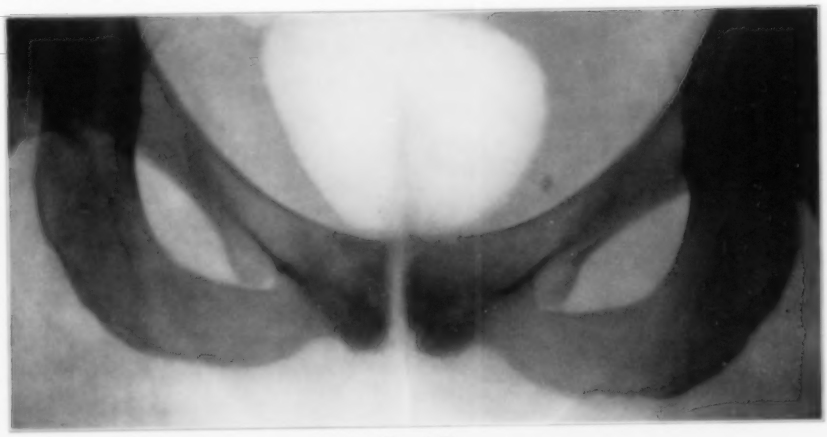


FIG. 1-E

This roentgenogram (June 19, 1952), made two and a half years after the onset of symptoms, shows that healing is progressing, although it is not complete. On either side of the pubic symphysis, there is an area of sclerosis which extends for about two and one-half centimeters.

The patient was last seen four months after delivery, at which time she had made an almost complete recovery.

CASE 8: Onset after pelvic surgery. A white female, thirty-nine years of age, had symptoms consisting of pain and tenderness in the symphysis pubis. On July 23, 1948, extensive anterior vaginal surgery, including cystocele and rectocele repairs, had been done, and on November 16, 1948, a dilation and curettage had been performed. The onset of symptoms occurred on January 15, 1949, approximately two months after the surgery. At no time was the pain intense, and although there was rather severe tenderness directly over the

Figs. 1-B (× 150) and 1-C (× 400): Microscopic report (November 11, 1950). These two sections show three segments of fibrocartilage and demonstrate vacuolization and focal fibroid degeneration. The section in Fig. 1-B also shows a proliferation of fibroblasts and endothelial cells. Vascular channels are being formed by these cells.

In the area shown in these two figures the cartilage has largely disappeared or remains as elongated hyalin remnants, and the fibroblasts are laying down collagen. No acute or chronic inflammatory cells are apparent, and there is no evidence of infection, either chronic or acute. The diagnosis is degeneration and fibrovascular metaplasia of the fibrocartilage.

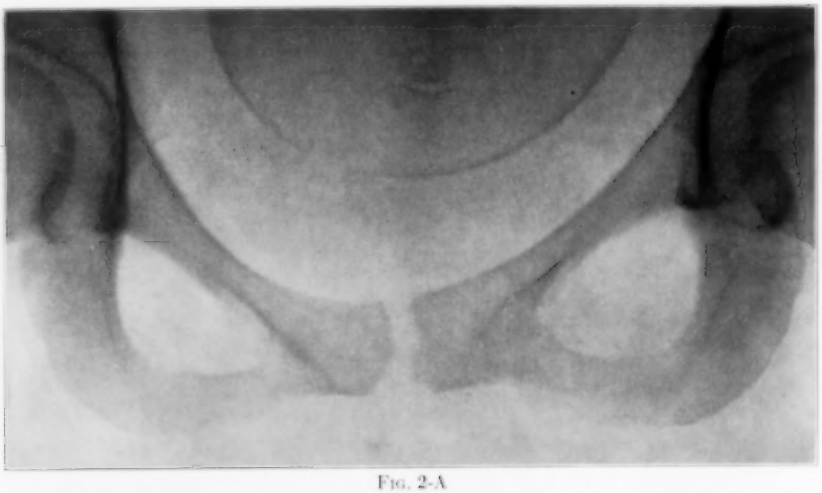


FIG. 2-A

Case 2 (Table I). Anteroposterior view (July 17, 1951), made for pelvimetry. The symphysis is smooth and normal, although definitely widened. The widening is presumably due to the pressure of the fetal head and to the relaxation of the ligaments.

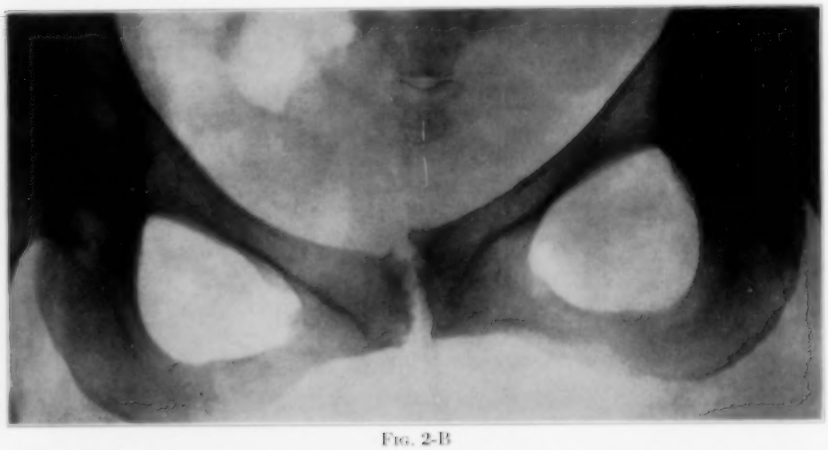


FIG. 2-B

This roentgenogram (July 13, 1952), made nine months after the onset of symptoms, shows spotty destruction of the bone about the symphysis, with slight sclerosis extending lateralward on either side for approximately one-half a centimeter.

symphysis, there was no swelling or fluctuation. The results of all laboratory tests, including blood count, urinalysis, and serological examination, were normal. The first roentgenogram, made ten and one-half months after the onset of symptoms, showed considerable narrowing of the symphysis with spotty demineralization and with sclerosis extending on either side of the symphysis for about two and one-half centimeters. Two years after the onset of symptoms, the tenderness had disappeared, but some pain remained when the patient walked or stood for long periods.

When the patient was last seen, three years after the onset of the trouble, the symptoms had completely disappeared. A roentgenogram made at that time showed much the same picture as the previous roentgenogram had shown, except that increased sclerosis was evident.

CASE 10: Onset of symptoms after trauma. On July 1, 1953, a white female, thirty-seven years of age, was in an automobile accident, the car in which she was riding being hit hard from the side by another car. At first, she did not think that she had been badly hurt, although she had some pain about the pelvis and the inner side of the right thigh. One month after the accident, however, she began to have pain in the region of the symphysis pubis, and a roentgenogram made at that time showed marked narrowing and sclerosis (Fig. 6).

FIG. 2-C

FIG. 2-D

Figs. 2-C and 2-D: Anteroposterior views (September 17, 1952), made when the patient was standing first on one foot and then on the other. Mobility of one-eighth of an inch is apparent at the symphysis, but no mobility is apparent at the sacro-iliac joints.

FIG. 2-E

Anteroposterior view (March 11, 1954), made three years and nine months after the onset of symptoms. The disease has healed, although roughening of the symphysis is still apparent.

The patient was able to get around, but the pubis remained very tender, and she was unable to abduct the thighs. She also had considerable pain in the lower portion of her back, and there developed a troublesome clicking sensation which seemed to emanate from the left groin. The clicking gradually stopped, however, and when she was last seen in August 1954, the condition had become asymptomatic. At no time was there any evidence of swelling or abscess formation about the pubis or ischium.

This patient had all the usual symptomatic treatment such as diathermy, irradiation with infrared rays, application of a corset, rest in a firm bed, and injections of vitamins. She also was given phenylbutazone, which did not help her at all; cortisone, which gave her relief for only two or three weeks; and x-ray therapy, which gave no relief. She had a definite emotional problem.

## REVIEW OF THE LITERATURE

In a review of the literature the authors were able to find reports of four cases which were similar to their own and which they felt represented the same disease. One of these

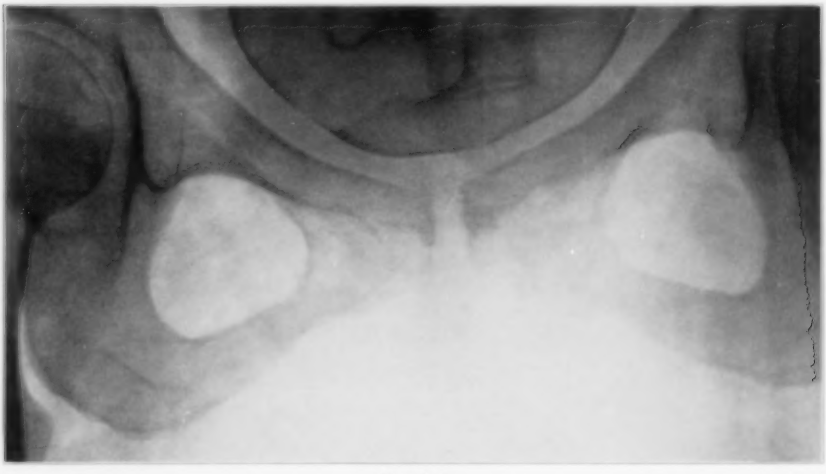


FIG. 3-A

Case 5 (Table I). Roentgenogram (February 4, 1952) of the pubic area, made at the onset of the trouble. Widening of the symphysis is apparent and also demineralization of the inferior borders of the pubic bones. No sclerosis can be seen, however. Note the fetal head in the pelvis.

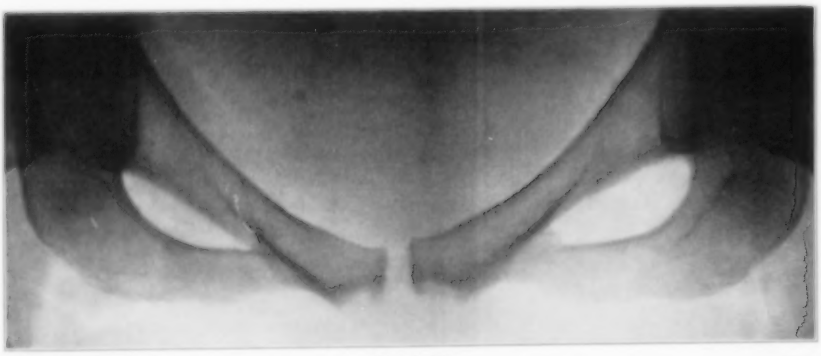


FIG. 3-B

This anteroposterior view (March 9, 1954) of the pelvis, made two years and three months after the onset of trouble, shows widening of the symphysis. The borders of this structure are smooth, but on the inferior border of the adjacent pubic bones there are areas of destruction and sclerosis.

FIG. 3-C

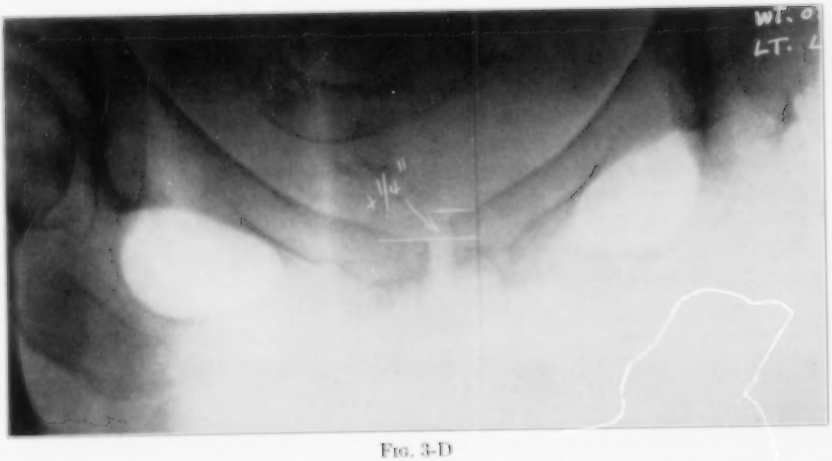



FIG. 3-D

Figs. 3-C and 3-D: Anteroposterior views (March 25, 1954) of the pelvis, made when the patient was standing first on the right foot (Fig. 3-C) and then on the left (Fig. 3-D). It is apparent that there is mobility of one-quarter of an inch at the symphysis. There appears to be no mobility at the sacro-iliac joints.

FIG. 4-A

Case 7 (Table I). This anteroposterior view (January 22, 1948) of the pelvis, made six months after the onset of symptoms, shows roughness and mottling about the symphysis; moderate sclerosis, extending lateralward for about two centimeters, is also apparent.

FIG. 4-B

Roentgenogram (April 5, 1949), made one year and nine months after the onset of symptoms. A marked increase in sclerosis has occurred since the roentgenogram in Fig. 4-A was made.

cases was originally reported as osteomyelitis [16], one was originally reported as osteoarthropathy [6], and two were originally reported as osteitis pubis [8, 13]. The prominent features of these four cases are presented in Table II.

The authors also found four cases [11, 19, 20, 22] which were quite similar to their own, but in which suppuration had occurred and in which abscesses had developed in the space of Retzius. Because of the latter factors the authors do not feel that these cases should be classed with theirs but mention them because the symptoms described have recently been referred to by several authors as probably representing osteitis pubis. The cases were originally reported as osteomyelitis.

## DISCUSSION

In order that the condition in the female may be better understood and that comparisons may be made, a discussion of the disease as it ordinarily occurs in the male is presented.

In the typical male patient the symptoms develop three weeks to four months after surgery, the usual operation being prostatectomy. The patient first experiences discomfort in the region of the symphysis pubis, this discomfort increasing until he is unable to move about in bed without excruciating pain. As the process spreads along the pubic

rami, the insertions of the adductor muscles are also affected, abduction of the thighs becomes agonizingly painful, and walking becomes impossible. The patient is then bed-fast. As the process further spreads to the ischial tuberosities, sitting also becomes unbearable, and occasionally, there is dysuria and pain on defection.

An examination reveals marked tenderness over the pubic bones and, often, over the

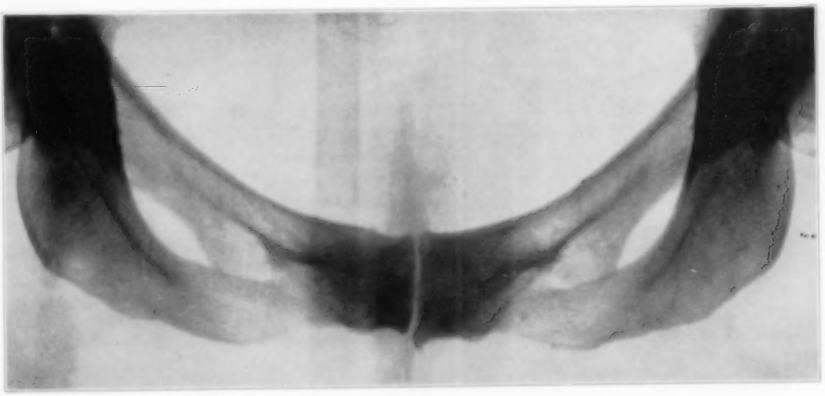


FIG. 5-A

Case 9 (Table I). This roentgenogram (February 22, 1946), made at the time of the initial injury, shows marked narrowing of the symphysis. It also shows an area of bony condensation extending lateralward from the symphysis for about two and one-half centimeters.

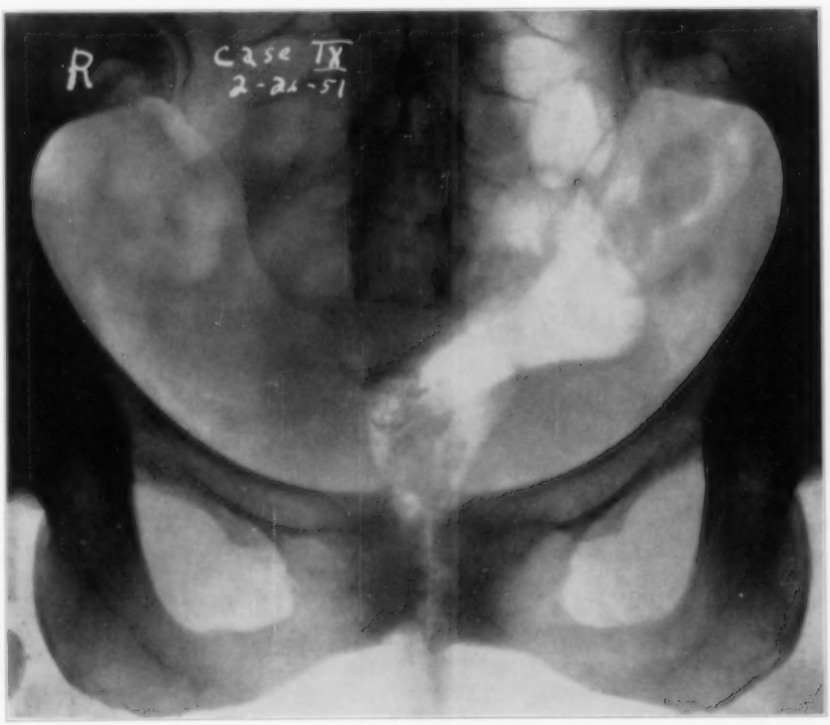



FIG. 5-B

This roentgenogram (February 26, 1951), made five years after the initial injury, demonstrates that there has been considerable condensation about the symphysis.

TABLE II
REVIEW OF LITERATURE

| Case | Age | Mode of Onset | Initial Symptoms and Findings | Fluctuation Abscess or Drainage | Biopsy |
|---|---|---|---|---|---|
| 1 | 28 | Six months after traumatic instrument delivery | Pain in region of symphysis | None | No evidence of infection |
| 2 | 32 | Second month of pregnancy | Pain in pubis on walking, tenderness over pubis | None | None |
| 3 | 53 | Following urological study | Severe pain in pubis, inability to walk | None | None |
| 4 | 68 | Three weeks after extensive bladder surgery | Severe pain in pubis, inability to walk | None | None |

ischial tuberosities as well. Usually there is no fever, but occasionally low-grade fever may be present during the early stages. As occurs with the female, the roentgenographic examination often gives negative results at first, but later reveals evidence of lifting and fraying of the periosteum, particularly in relation to the muscle attachments. Gradually irregularity of the pubic bones with spotty resorption appears, and the symphysis pubis shows notching and moderate widening.

In the majority of cases, the process slowly resolves and within six months to a year, the patient is perfectly well. The appearance of the bone as shown by roentgenograms does not return to normal until some time after the bone has actually recovered, as shown by clinical tests. Treatment is ordinarily symptomatic; and in the male, as in the female, the disease is self-limited with the result that any treatment that is used may give the impression of being of more value than it actually is.

Regarding the relationship between the disease of the female and the more common disease of the male, the authors believe that they are variants of the same disease and that both originate from the same basic cause. Their symptoms are very similar. The male patients are generally a little sicker than the female, but from the standpoint of pain alone, there is little difference. In both sexes, the symptoms develop following trauma to the structures about the symphysis. In the females whose cases are reported here, only the pubis was involved, and in none of these patients did the disease extend to the ischium, as it commonly does in the male.

## ETIOLOGY

Several etiological hypotheses concerning this condition have been advanced in the past. None of these hypotheses have been satisfactory, however, and the cause of the condition is still an enigma. Some of the more important of the hypotheses that have been advanced are as follows:

I. The most widely accepted belief is that the process is caused by an infection which develops in the periosteum following leakage of bacteria-laden urine into the retropubic space. This belief is supported by the fact that in several cases organisms have been cultured from the diseased area. The infection theory is far from universally accepted, however, and there is probably more evidence for the view that infection is not the cause of the disease but is only an incidental finding in some cases. Among the facts that seem to militate against infection as the cause of the disease are the following:

TABLE II
REVIEW OF LITERATURE

| Treatment | Roentgenographic Changes | Follow-Up Time | Status When Last Seen | Reported By |
|---|---|---|---|---|
| Curettement plus symptomatic treatment | Small cavity adjacent to symphysis | Nine months | Complete healing | Painter |
| Complete bed rest, corset | Wide interval at symphysis | Few months | Complete recovery | Davis |
| Bed rest, sedation, spica cast | Widening and rarefaction at pubis | Eleven months | Recovery | Kleinbery |
| Corticotropin | Mottling and sclerosis about pubis | One year | Recovery | Gelber and Byron |

1. The condition is nearly always bilaterally symmetrical. Infection ordinarily does not cross the symphysial cartilage and it would seem unlikely that osteomyelitis would develop in both sides at the same time in practically all cases.

2. Recovery is spontaneous in all cases.

3. In most cases there is no abscess formation. Mortensen reported that in forty-four cases no abscesses were seen, and in many cases cultures have been made without any organisms being found.

4. Severe pain occurs, but not the severe systemic symptoms of an osteomyelitic infection. In many cases, the blood count and temperature remain normal throughout the duration of the symptoms.

5. In most cases healing occurs without there being any excess bone formation.

6. Experimentally, it has not been possible to reproduce the disease by injecting cultures of organisms under the periosteum of the pubis in rabbits (Wheeler).

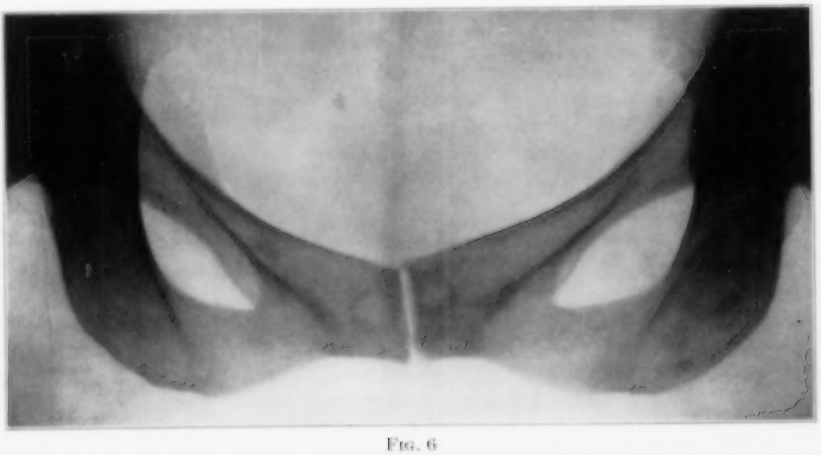


FIG. 6

Case 10 (Table I). This anteroposterior view (August 14, 1953) of the pelvis, made one and one-half months after the original injury, shows considerable narrowing and sclerosis of the symphysis pubis. Near the mid-line there is evidence of an old cystic change which has healed.

FIG. 7-A

Case 11 (Table I). Anteroposterior view (April 24, 1951) of the pelvis, made for pelvimetry two weeks before the onset of symptoms. The symphysis is wider than usual, but there is no evidence of change in the adjacent bony structures. A large foetus may be seen in the pelvis.

II. Another hypothesis is that the condition occurs when the periosteum of the pubis has been injured by the application of traction on the rectus, by the pressure of drainage tubes, by the insertion of a local anaesthetic needle, or by the spillage of urine.

III. A third hypothesis is that the condition arises from a low-grade pelvic cellulitis which has spread through the lymphatic vessels. The increased supply of blood due to the inflammation adjacent to the bone causes spotty demineralization.

It might also be mentioned that the condition simulates acute bone atrophy and so resembles Sudeck's atrophy (Wheeler).

*Authors' Etiological Concept*

In considering the cause of this condition, the authors were impressed with the following facts:

1. There was no evidence of infection in any of their cases. The material biopsied from the patient in Case 1 showed no evidence of infection or even of inflammation.

2. In most of their cases, the pain was considerably more than what one would expect on the basis of the pathological symptoms that were present.

3. Spontaneous recovery occurred within a few months to three years.

4. The roentgenograms disclosed, first, a mottled rarefaction and, later, sclerosis of the affected bone. These changes were bilaterally symmetrical.

5. In each case, some event or condition capable of producing trauma had occurred. In the five patients in whom the symptoms appeared during pregnancy, trauma could have been caused by motion at the pubis during walking, for there is a definite relaxation of the ligaments about the pubis during pregnancy. The authors reviewed one hundred and fifty roentgenograms made for pelvimetry, and in eleven of them found evidence of widening at the symphysis. This widening was as much as one-half of an inch and was presumably due to the relaxation of the ligaments about the pubis and to the pressure of the fetal head in the pelvis. (Another study of this symptom is being made.) The condition in the five patients in whom the symptoms appeared after parturition could have been due to the trauma of delivery superimposed upon the softened and relaxed condition of the ligaments. In two cases (9 and 10), the symptoms appeared following a known injury. (In four males whose cases have been reported in the literature [1], an injury to the pubis was definitely the

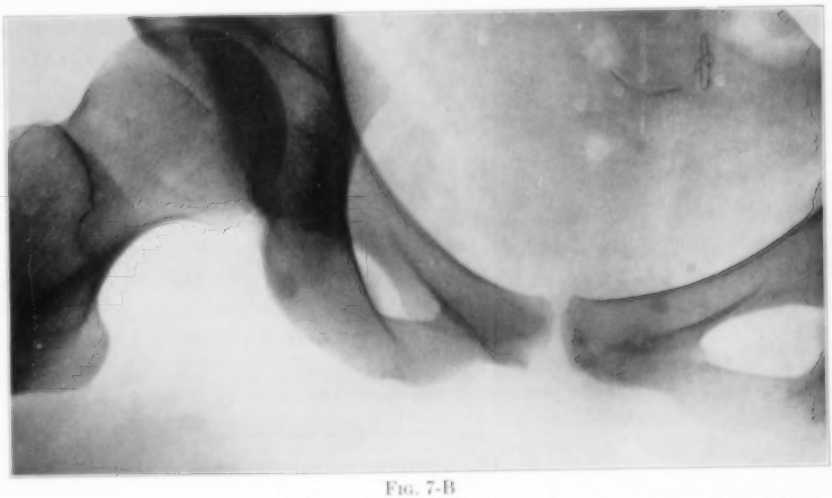


FIG. 7-B

This anteroposterior view (July 2, 1951) of the pelvis, made six weeks after the onset of symptoms, shows roughening of the symphysis. An area of destruction with a diameter of about one centimeter is apparent on the inferior surface of the right pubic bone.

inciting factor.) In one case (Case 8), the symptoms came on after extensive surgery in the retropubic and infrapubic areas.

6. In ten of the authors' thirteen patients, the symptoms appeared at a time when profound endocrine changes were occurring in the body,—that is, during and shortly after pregnancy. It has been shown experimentally [9] that small doses of estrogen, when injected into a castrated female mouse, cause rather marked changes at the symphysis pubis. The solid symphysial parts of the bone gradually disappear and are replaced by vascular tissue which contains many nuclei and which is thought to be derived from the marrow of the bone. After prolonged treatment, this tissue forms a collagenous ligament which fills the interpubic gap. If relaxin is given with the estrogen, there occurs a rapid and extensive reabsorption and separation of the bones at the symphysis and a proliferation of a collagenous ligament. These changes resemble those that occur about the symphysis of the human during a normal pregnancy.

7. Five of the authors' thirteen patients were under the care of a psychiatrist at some time during the course of the disease. It is held by many observers that reflex sympathetic dystrophies are more common in highly emotional people.

Taking into account the above facts, the authors evolved the following concept. Admittedly, this concept leaves some factors unexplained. The condition referred to as osteitis pubis is a localized reflex neurovascular dystrophy which is brought about by a combination of trauma and predisposing changes at the symphysis. The changes at the symphysis are due to the influence of certain hormones and are of the nature of, but more pronounced than, those which normally occur during pregnancy.

## INCIDENCE

The authors have no statistics regarding the incidence of this disease. They believe, however, that it is quite rare, although not as rare as the few reports in the literature might lead one to believe. In their review of 150 roentgenograms made for pelvimetry, they found no changes that could be diagnosed as osteitis pubis and so feel that many of the milder cases of this disease go unrecognized.

## TREATMENT

In all but one of the authors' cases, the treatment was symptomatic consisting in

bed rest, warm packs, and analgesics. In the other case (Case 10) the patient was attended by a number of doctors and so received a variety of treatments, including x-ray therapy, ACTH, cortisone, and phenylbutazone.

SUMMARY

The non-suppurative, non-inflammatory disease of the anterior pelvic girdle which occurs in the female appears to be a variant of the more common disease which occasionally follows suprapubic prostatectomy in men. Treatment should be symptomatic, although x-ray therapy, cortisone, ACTH, and possibly phenylbutazone may be of value. The disease is self-limiting, and the authors do not believe that in their cases infection played any part.

NOTE: The authors wish to express their thanks to Dr. Howard Mendelsohn of Los Angeles for the privilege of using three of his cases (Cases 3, 4, and 5); to the doctors of Harriman Jones Clinic and Hospital in Long Beach for permission to review their pelvimetry file and to use one of their cases (Case 9); and to Dr. C. W. Lambert of Pasadena for permission to use two of his cases (Cases 11 and 12).

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# Tumors of the Hand *

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In the treatment of tumors of the hand, many varied and interesting problems are encountered. The tumors which occur in the hand arise from the skin, subcutaneous tissue, tendons, nerves, blood vessels, and bones, and are of many different types. Some of these types occur only in the hand, and some occur in other parts of the body as well. In addition to primary tumors, metastatic lesions occur, although only rarely [7]. A tumor of the hand may arise in a number of ways. It may be a manifestation of some generalized disorder such as gout, or it may be evidence of a disturbance in fat metabolism, such as occurs in xanthomatosis. It may also be the result of an injury, for the hand is constantly exposed in daily life and is subjected to a good deal of trauma. The precancerous and cancerous group of tumors are especially apt to occur in this manner. Neoplasms of the hand range from benign growths which mar the appearance of the hand or perhaps mildly impair its function, to malignant lesions that eventually lead to death. In many cases, the tumor can be readily diagnosed, but occasionally it must be carefully exposed and examined before a diagnosis can be made, and in rare instances it is even necessary to examine a specimen under the microscope. Tumors of the hand can occur in persons of any age, and even a newborn infant may have a tumor that requires surgery. On the other hand, certain types of tumor, especially the premalignant and malignant tumors of the skin, are found only in the older age group. Tumors of the hand are found in persons of both sexes and in persons of all races and walks of life.

Several good summaries concerning tumors of the hand have been written in the past, and the author has found these very valuable [9, 29, 31, 32, 47, 50, 56].

The author has encountered 147 cases of tumor of the hand. A breakdown of the types of tumors found in these cases is given in Table I.

## GENERAL CONSIDERATIONS

In the performance of surgical procedures involving tumors of the hand, certain general considerations must be remembered. If the tumor to be treated is relatively small, the necessary surgery can often be performed in the out-patient department. If the tumor is large and deeply situated, however, and if it requires a prolonged operation, the surgery should be performed in a well equipped operating room where the best possible facilities are available. It is always necessary to give the patient a thorough physical examination and to obtain his complete history. In cases of lesions of possible malignancy, the regional lymph nodes should be carefully examined, and, when indicated, roentgenograms of the chest should be obtained. A routine blood count and urinalysis are always essential, and adequate anaesthesia is, of course, important. Dissection of a tumor mass is carried out in a bloodless field, a blood-pressure cuff being employed as a pneumatic tourniquet.

The same general principles that apply to other types of hand surgery apply to the removal of tumors. Care must be taken to protect the small digital nerves and vessels which often lie adherent to the tumors. In the palm incisions should follow the transverse flexion creases; in the finger they should be mid-lateral in location. The surgeon must be prepared for any eventuality, for at times it may be necessary to carry out rather extensive procedures, including tendon-grafting and nerve-grafting. This is especially true in

* Read at the Annual Meeting of the American Society for Surgery of the Hand, Los Angeles, California, January 28, 1955.

TABLE I

TUMORS ENCOUNTERED BY THE AUTHOR

| Type of Tumor | No. of Cases |
|---|---|
| Premalignant and carcinomatous tumors | 11 |
| Fibromata | 3 |
| Lipomata | 5 |
| Ganglia | 51 |
| Ganglia on the distal joints of the fingers | 7 |
| Chronic tenosynovitis | 7 |
| Tuberculous tenosynovitis | 5 |
| Giant-cell tumors | 12 |
| Glomus tumors | 8 |
| Epidermoid cysts | 6 |
| Pyogenic granulomata | 4 |
| Foreign-body granulomata | 2 |
| Blood-vessel tumors | 8 |
| Tumors of the peripheral nerves | 5 |
| Bone tumors | 6 |
| Fibrosarcomata | 2 |
| Lymphatic cysts | 2 |
| Fibrolipoma of the wrist | 1 |
| Synovial cysts of skin | 1 |
| Boeck-sarcoid | 1 |

cases of large tumor masses which sometimes destroy tendons or nerves. Fine suture material is used for ligating vessels, and fine silk or nylon preparations are used to suture the skin. If extensive bleeding and oozing have occurred, it may be necessary to insert several small drains and to continue the use of these drains for twenty-four to forty-eight hours.

Immediately after the operation the hand is splinted in the position of function and a compression dressing is applied. When the patient is in bed, the arm is elevated on several pillows, and when he is ambulatory, it is carried in a sling. He is instructed to remove the sling several times a day in order to exercise his shoulder and elbow. The dressing is loosened the day after the operation, and the drains are removed approximately forty-eight hours after the operation. The hand is kept splinted for seven to ten days, after which time the wound should be well healed and the sutures can be removed. Motion is restored as soon as it is feasible. Adequate follow-up is essential in cases of potentially or actually malignant lesions.

## TUMORS ARISING FROM THE EPITHELIUM *

One of the most common tumors that arises from the skin is the wart. Frequently this tumor disappears spontaneously, but occasionally it has to be removed by surgery. In such cases the entire growth should be excised and the skin should be closed with sutures. In rare instances, a skin graft is also necessary.

Molluscum contagiosum also occurs on the hand. The lesions produced by this condition are similar to warts and, like warts, usually disappear spontaneously.

Both premalignant and malignant tumors arise on the hand. Premalignant tumors, of which there are many, occur when the skin has been irritated by such factors as x-rays, the rays of the sun, and chemicals. Malignant tumors may arise as the result of such causes as chronic infections, burn scars, or arsenicals [15].

Keratosis is a type of premalignant tumor found in older people who have been frequently exposed to the weather. On the hand these tumors always appear on the dorsum and they should be observed for signs of malignant change. If they occur singly, they may be excised (Fig. 1).

* In the presentation of these tumors, the outline used by Dr. Deryl Hart has been generally followed [23].

FIG. 1

FIG. 2

Fig. 1: A keratotic lesion on the dorsum of the hand. The lesion and the immediately surrounding tissues were excised, and the resulting wound was closed primarily.

Fig. 2: X-ray dermatitis in a dentist forty-five years of age. Over a period of twenty years the involved hand of this dentist had been frequently exposed to roentgen rays. The entire lesion was excised, and the defect was covered with a free full-thickness skin graft. A good functioning finger was obtained.

FIG. 3-A

FIG. 3-B

Fig. 3-A: A squamous-cell carcinoma on the dorsal aspect of the hand. The involved tissues were excised, and a skin graft was applied to the resulting defect. There has been no recurrence of the tumor in five years.

Fig. 3-B: A squamous-cell carcinoma on the dorsal aspect of the left ring finger. Chronic irritation, due to the presence of a foreign body, was the cause of this tumor. The entire carcinoma was excised along with the surrounding area, and a free full-thickness skin graft was applied. In the ensuing two years there has been no recurrence.

FIG. 4-A

A squamous-cell carcinoma on the left index finger of a dentist. The tumor developed in the presence of a chronic infection.

Roentgen-ray dermatitis[49, 71] is also considered a premalignant tumor. This tumor is not as common as it was at one time, but isolated cases are still encountered. The patients with this tumor are usually doctors, dentists, or other persons who have been exposed to large doses of x-rays under a fluoroscope (Fig. 2). Excision of the entire involved area is indicated, and the defect should be replaced by a free full-thickness skin graft. If malignant changes have occurred, dissection of the regional lymph node is necessary.

Trauma and chronic infection may both contribute to the development of carcinomata of the hand[13, 14, 36, 48]. These malignant lesions may also arise from a previous skin tumor or from normal skin. It is said that only 5 to 10 per cent of cutaneous carcinomata occur in the hand and foot [48]. Among these, squamous-cell and basal-cell carcinomata are both encountered, although squamous-cell carcinomata are by far the more common (Figs. 3-A and 3-B).

Squamous-cell carcinoma is usually located on the dorsum of the hand. If it is allowed to grow, it eventually involves the tendons, bones, and muscles; hemorrhage may occur if large vessels are eroded. Treatment consists in excision of the tumor and the surrounding area and in the application of a skin graft to cover the defect. If palpable nodes are present in the regional areas, they should be removed approximately two weeks after the tumor has been excised. Approximately six weeks later prophylactic dissection may also be performed, or, if this procedure is not done, the patient may be observed and the axillary and epitrochlear nodes removed if enlargement occurs. A squamous-cell carcinoma rarely metastasizes from x-ray dermatitis, since the process requires a period of years. Study of a gross specimen of this tumor reveals the presence of an ulcerated area with an irregular outline and a hard border, and microscopic study demonstrates that it is composed of columns of squamous epithelial cells which resemble epithelial pearls.

When basal-cell carcinoma occurs in the hand, it has the typical appearance of a rodent ulcer, being composed of an area of rolled-up indurated tissue. Metastases of this tumor to the lymph nodes are rare.

An example of a type of carcinoma which arises from a chronic infection is carcinoma of the nail (Figs. 4-A and 4-B). This lesion is of the squamous-cell type and occurs in the presence of an infection which has remained unhealed over the course of a year or two. Treatment consists in amputation of the involved digit, and secondary dissection of the epitrochlear and axillary nodes. The tumor is quite rare, and up until 1939, only nineteen cases had been reported in the literature [42]. The patient in the author's series was a fifty-year-old dentist who had had a chronic paronychia for eighteen months.

Benign moles are found on the hand as well as on other parts of the body. If they are subject to irritation or if they appear to be increasing in size, they should be removed. Surgical excision of the entire mole and its surrounding tissue is considered the best

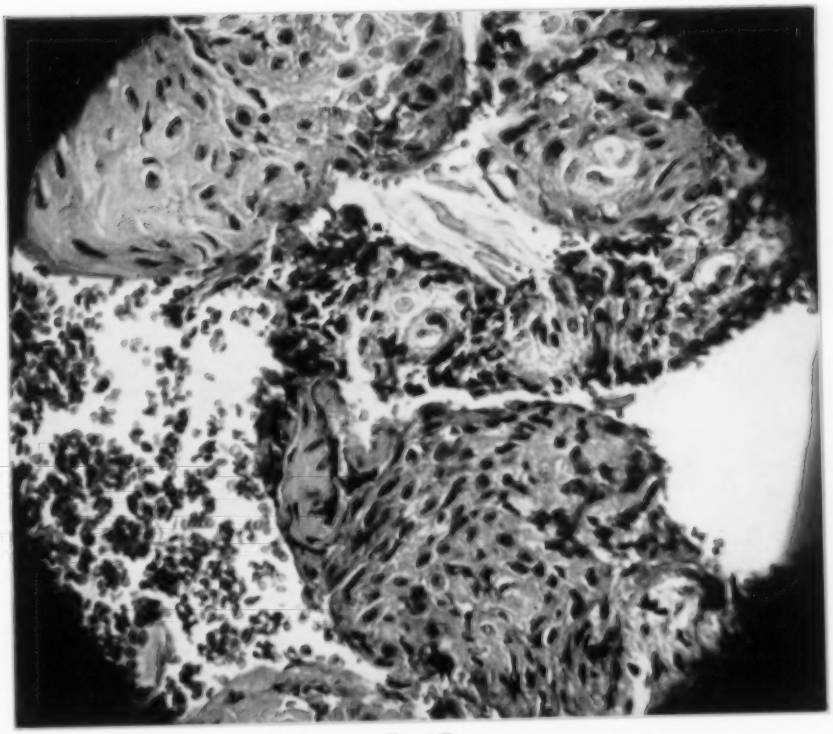

FIG. 4-B

A microscopic view (× 430) of the carcinoma shown in Fig. 4-A. The involved finger was amputated, and dissection of the axillary and epitrochlear nodes was performed.

method of removal. Biopsy of a limited area is considered unsatisfactory, and the performance of cautery, electrodissection, or irradiation is contra-indicated [50] (Fig. 5).

Benign moles in the subungual area may give rise to malignant melanoma (Hutchinson's melanotic whitlow) [3, 22, 63, 77], for moles under the nail are constantly subjected to trauma, and 50 per cent of malignant melanomata arise from a traumatized area. For this reason benign subungual moles should be removed.

The most common location of malignant melanoma is on the thumb. First there appears an infection which soon separates the nail from the nail bed. An ulcer-like growth then begins to develop. The main body of the growth may be with or without pigmentation, but many times a certain amount of pigmentation is present at the periphery (Fig. 6). A microscopic study of the tumor reveals that inflammation is present in addition to the ulcerating mass and that the tumor is composed of fusiform cells, which have hyperchromatic nuclei and a pigment that is both intracellular and extracellular; infrequent mitosis occurs. Treatment consists in early amputation of the digit and in removal of the regional lymph nodes, this removal being performed either immediately after the amputation or approximately two weeks later. In regard to prognosis, the best possible chances of achieving a cure are in cases of the subungual type of tumor. For all subungual melanomata, Pack reports a five-year-survival rate of 18.75 per cent, there being no evidence of recurrence in any of the surviving patients.

## TUMORS ARISING FROM CONNECTIVE TISSUE

### *Fibromata* [28, 40]

Fibromata do occur on the hand but only rarely. Two types of this tumor have been

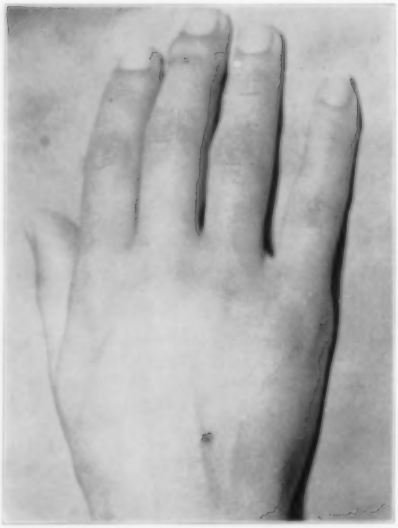

FIG. 5

FIG. 6

Fig. 5: A naevus on the dorsal aspect of the right hand of a thirty-year-old social worker. The lesion was excised, and there has been no new growth in the year since the operation was performed.

Fig. 6: Melanotic melanoma in a forty-four-year-old factory employee. She was seen for examination in February 1953. She had suffered an injury to the nail of her right thumb on a drill press in August 1948, and chronic infection had ensued. Repeated biopsies made at yearly intervals had been reported as being negative, and treatment had consisted in removal of the nail, incision and drainage, x-ray and ultra-violet-ray treatments, and the injection of penicillin, locally and systemically. When first seen by the author, the lesion appeared to be a melanoma. Wide excision was recommended and carried out, a malignant melanoma being encountered. Subsequently, on March 13, 1953, amputation of the thumb, along with epitrochlear and axillary lymph-node dissection, was carried out. The patient worked at intervals but eventually, on April 30, 1955, died as a result of widespread metastasis.

FIG. 7-A

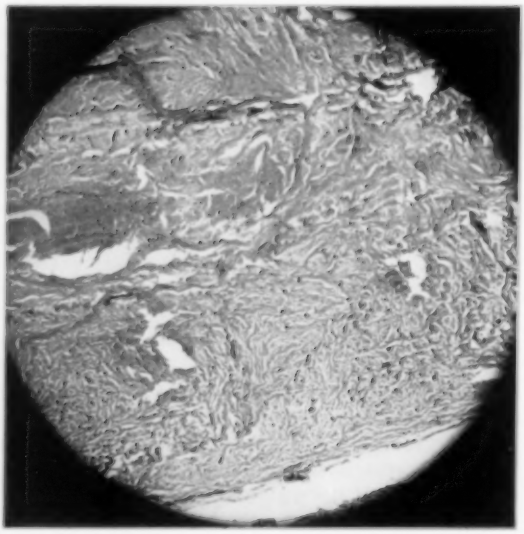

FIG. 7-B

Fig. 7-A: A fibroma on the dorsal aspect of the right middle finger. The tumor was completely excised, and there has been no recurrence.

Fig. 7-B: A microscopic view (× 90) of the tumor shown in Fig. 7-A. Note the presence of dense fibrous connective tissue arranged in bundles.

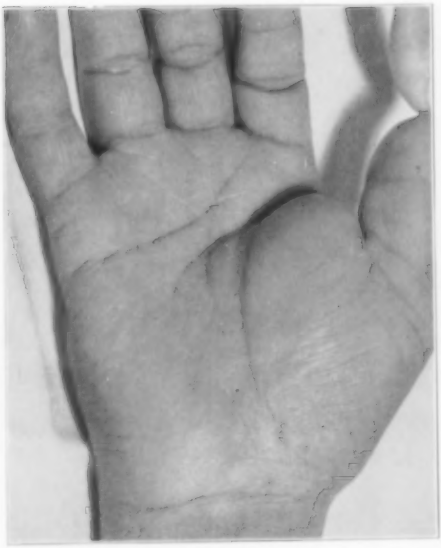

FIG. 8

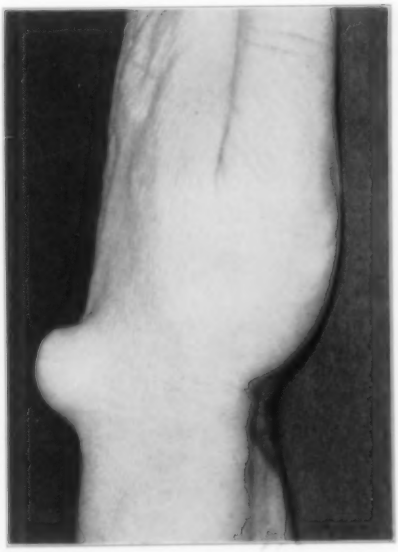

FIG. 9-A

Fig. 8: A lipoma on the thenar eminence of a colored woman.

Fig. 9-A: A recurrent ganglion on the dorsoradial aspect of the right wrist. Complete excision was done, and there has been no further recurrence.

noted, a deep type which arises from the joint capsules and a superficial type. The cause of this tumor is not known. A study of the gross specimen reveals that it is well encapsulated, and a microscopic study demonstrates the presence of dense fibrous tissue in sheets or whorls. If the tumors are soft, their structure is mainly cellular. The tumors are located on either the palmar or dorsal aspect of the fingers, and the differential diagnosis is epidermoid cyst, ganglion, or xanthoma. Treatment consists in removal of the entire structure, the prognosis for cure being good (Figs. 7-A and 7-B).

*Lipomata* [1, 7, 68, 69, 70, 74]

Lipomata of the hand are not too rare, and resemble the lipomata that occur elsewhere on the body. Grossly they are soft, well encapsulated tumors, and microscopic study reveals that they contain fatty and fibrous tissue. Their cause is unknown. Lipomata are frequently found on both the volar and dorsal aspects of the hand, although in the author's cases they were more common on the former than on the latter. Mason [47] states that they can be divided into two groups, a superficial or subcutaneous group and a deep or subfascial group. He also says that the latter group can be further subdivided into an epivaginal and an endovaginal group. When a soft palpable tumor is encountered, the diagnosis can be made quite easily, for an application of an ice bag to the area will chill the fat enough to harden it. Treatment should be by excision, with preservation of the vessels and nerves; and the prognosis for a cure is good. Occasionally it is rather difficult to distinguish the clinical symptoms of a lipoma from those of an xanthoma or of a tuberculous tenosynovitis.

The symptoms that are produced by lipomata are due to mechanical disturbances. In the author's series of five cases, three of the tumors occurred on the volar surface of the finger and two occurred on the palm; one of the latter was in the thenar eminence and one was in the hypothenar eminence. According to recent articles in the literature, the two in the palm are the thirteenth and fourteenth that have occurred in this region and are the third and fourth that have occurred in this region in a Negro (Fig. 8).

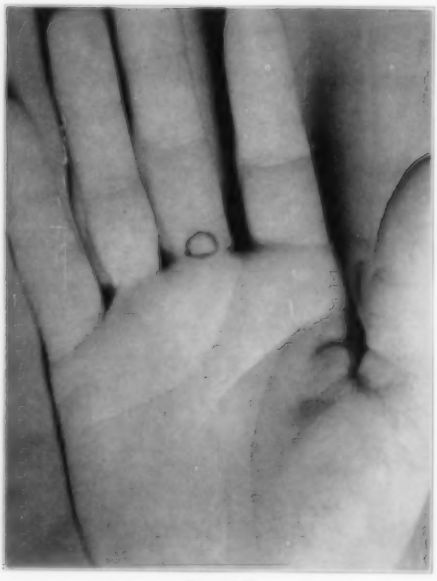

FIG. 9-B

FIG. 9-C

Fig. 9-B: Outline of a ganglion on the tendon sheath of the right middle finger.

Fig. 9-C: Appearance at the time of surgery of a ganglion on the flexor tendon sheath of the right middle finger.

*Ganglia* [11, 19, 38]

Ganglia are the most common tumors that are found on the hand. In about one-third of the cases reported these tumors have been attributed to trauma. At one time it was thought that they arose from a degeneration of the connective tissue around the joints similar to adventitious bursas [8], but it has also been thought that they represent a true herniation of the joint. Some authors today feel that they are synovial tumors which have arisen from the synovial membrane and from the fibrous tissues that enter into the formation of tendon sheaths and joint capsules.

Ganglia arise from the tendon sheath, occasionally occurring between the fibers of the tendons themselves. They are found most often on the dorsal aspect of the wrist, between the extensor pollicis longus and the extensor tendons to the index fingers, over the greater and the lesser multangulars. The next most common site is the volar aspect of the wrist, between the tendons of the brachioradialis and the flexor carpi radialis. In this location the cyst lies close to the radial artery, and the latter structure has to be retracted before the ganglion can be freed from the surrounding tissue. Another common site is the sheath of the flexor tendons of the fingers, over the proximal phalanx. The tumor in this site is quite hard and is thought to arise from the bone (Figs. 9-A, 9-B, and 9-C). Ganglia also occur on the tendons themselves, sometimes giving rise to such phenomena as snapping-thumb or snapping-finger.

In the author's series there were fifty-one cases of ganglia. With very few exceptions the patients in these cases were women. Thirty of the fifty-one ganglia were found on the wrist, twenty-three of these being on the dorsoradial aspect, five being on the volar aspect, and one being on the dorsal-ulnar aspect. The remaining ganglion of the wrist was found adherent to the flexor carpi radialis. Of the other twenty-one ganglia, fourteen were found over the tendon sheaths of the digits, four were in the thumb, two in the palm, and one in the index finger (on the tendon fibers of the extensor digitorum communis).

A number of methods of treatment other than surgery have been suggested. One such

method is to rupture the cyst with a heavy object. Another method recently recommended is the aspiration of the contents of the cyst and the injection of the cyst with hydrocortone. The author has used this type of procedure, but in every instance he has had to resort to surgery. In some cases the cysts disappear spontaneously.

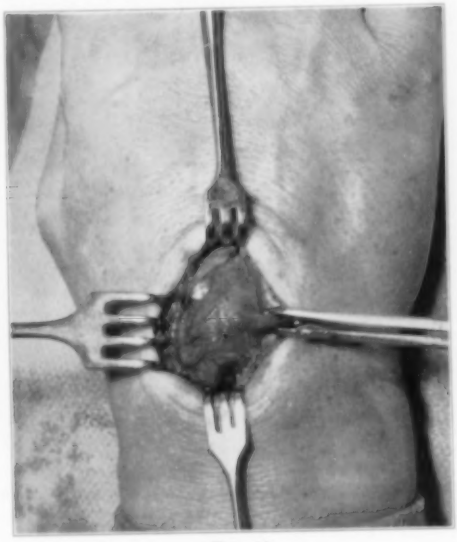

FIG. 10

FIG. 11-A

Fig. 10: Chronic tenosynovitis, involving the extensor tendons of the dorsal aspect of the right wrist. The involved tendons were dissected free from the tumor mass. There has been no recurrence of the tumor in the year since this surgery was done.

Fig. 11-A: A large swelling on the palm and wrist of the right hand.

FIG. 11-B

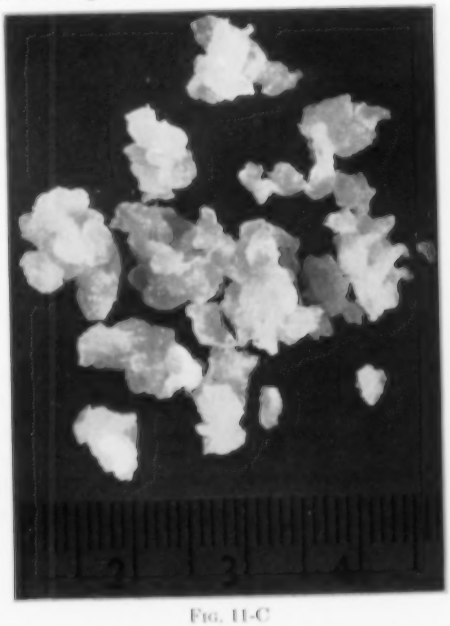

FIG. 11-C

Fig. 11-B: Chronic tuberculous tenosynovitis.

Fig. 11-C: Rice bodies obtained at the time of surgery. The lesion has not recurred since the operation, but flexion of the ring and little finger has remained limited.

FIG. 12-A

FIG. 12-B

Fig. 12-A: Giant-cell tumor on the volar aspect of the index finger. Total excision was done, and three years after the surgery there is no evidence of new growth.

Fig. 12-B: Giant-cell tumor on the little finger. Note the rather diffuse enlargement of this finger. Excision was performed, the flexor tendon being preserved, and a good return of function was obtained. There has been no recurrence of the tumor in the three and one-half years since the surgery was done.

Occasionally the exploration of a diffuse tumor on the dorsal aspect of the wrist reveals a cyst-like mass that completely surrounds all of the tendons. Preoperatively this mass is usually diagnosed as a ganglion, but the later diagnosis of the pathologist is usually chronic tenosynovitis or chronic villonodular tenosynovitis. Culture of the thin yellowish material contained in the mass reveals no organisms. Complete surgical excision of the mass results in a cure, and the author has seen no cases in which there was a recurrence. In the author's series there were seven cases of this condition.

Another condition which poses a problem of differential diagnosis is tuberculous tenosynovitis. Preoperatively a diagnosis of ganglion or compound ganglion is usually made, but when the cyst is opened, the straw-colored fluid and the rice bodies characteristic of tuberculous tenosynovitis are noted. In the author's series there were five cases of this condition. In one patient the dorsum of both hands and feet were involved, and in two patients destruction of the tendons was observed. This group of cases and the seven cases previously described are probably related and should all be described as tuberculous tenosynovitis of the hand [46] (Figs. 10 through 11-C).

Seven of the tumors that occurred on the distal interphalangeal joints of the fingers were found among patients in the older age group and appeared to be related to gout. Some of these tumors represented the recurrence of tumors that had previously been excised elsewhere, and all of them resembled small ganglia that had apparently arisen directly from the joint. Total excision of the joint produced a cure in every case but one; in this case the tumor recurred.

*Giant-Cell Tumors* [23, 54, 65]

Giant-cell tumor is one of the more common tumors of the hand. The cause of these tumors is unknown, but it is thought that trauma may be involved.

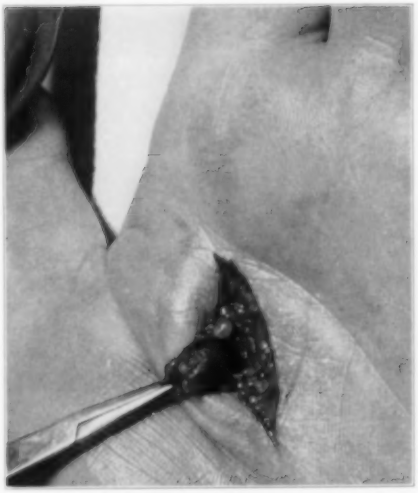

FIG. 13-A

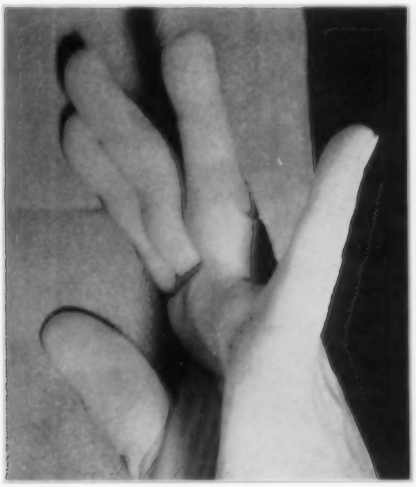

FIG. 13-B

Fig. 13-A: Glomus tumor on the palm of a seventy-year-old physician. This patient had had symptoms for a year, his chief complaint being that he experienced pain and soreness when he drove his car. Removal of the tumor resulted in relief of pain.

Fig. 13-B: Glomus tumor on the right ring finger of a fifty-five-year-old woman. This patient stated that she had had trouble for twenty years and that the pain was severe. A remarkable relief of pain followed removal of the tumor.

FIG. 13-C

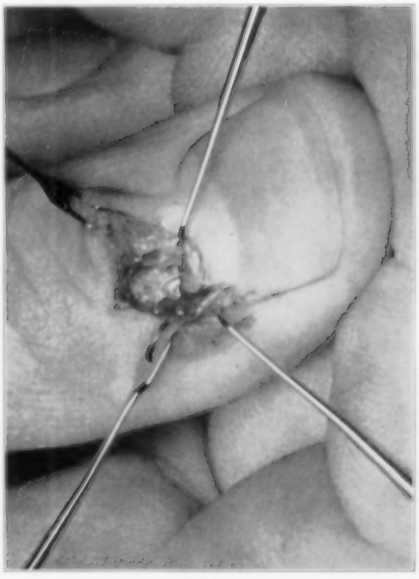

FIG. 13-D

Fig. 13-C: Roentgenogram of a glomus tumor. Note the severe erosion of the bone.

Fig. 13-D: Glomus tumor in the subungual area of the right thumb of a thirty-year-old physician. During the previous few years, he had had intermittent pain which had gradually become more severe. Excision of the tumor resulted in immediate relief of pain. The nail of this patient is deformed, but not severely so.

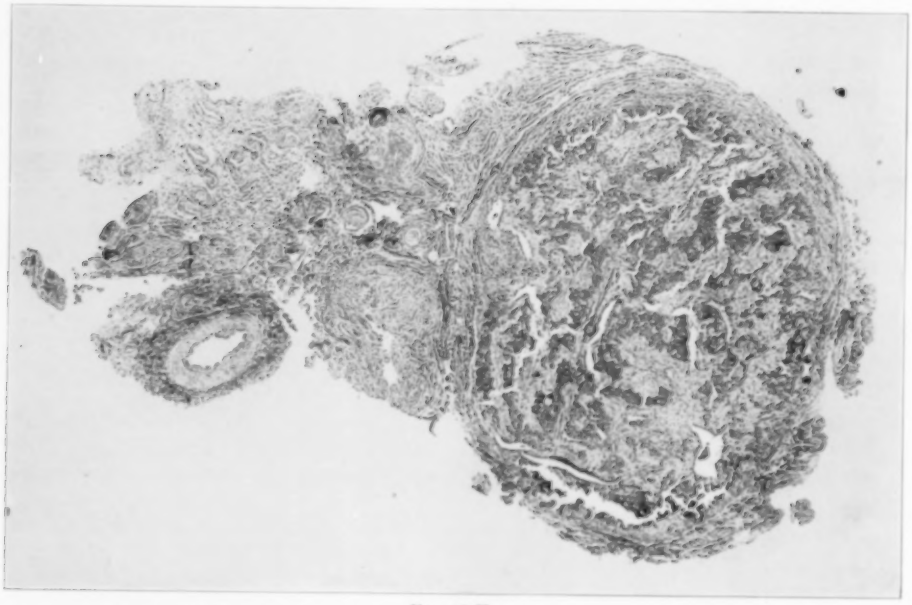

FIG. 13-E

Low-power photomicrograph (× 90) of the encapsulated glomus tumor.

The gross specimens are yellow or yellowish-brown with streaks of gray, and a microscopic study shows that they characteristically contain foam cells, foreign-body giant cells, and spindle-shaped cells. In the author's series they occurred most often on the volar aspect of the hand, but in general they occur on the dorsal aspect as well. They arise from the tendon sheath and, when on the volar aspect of the hand, often extend behind the tendon. For example, if they occur on the sheath of the flexor tendon, they arise from the dorsal part of this sheath. Occasionally these tumors invade the bone. The diagnosis is made by means of palpation and is based on the presence of a hard irregular mass that is not movable. At times it may be hard to distinguish these tumors from lipomata or ganglia.

The treatment of giant-cell tumors consists in excision. The neoplasm is benign and, if it is entirely removed, will not recur. The rate of recurrence for these tumors is said to be 10 per cent (Figs. 12-A and 12-B).

In the past the terms xanthoma and giant-cell tumor have been rather loosely exchanged. After observing fifty patients in whom these tumors occurred during a twenty-year period, Stevenson [65] stated that there is a definite difference between the two growths. The xanthoma is composed of tissue which infiltrates widely, while the giant-cell tumor is encapsulated. Furthermore, xanthoma are unlike giant-cell tumors in that they occur symmetrically in the fingers, elbows, buttocks, knees, ankles, heels, and toes and in that they are associated with a high cholesterol level.

The author has encountered twelve cases of this neoplasm. For nine cases, the pathologists returned a diagnosis of giant-cell tumor; for two others, they returned a diagnosis of xanthofibroma of the tendon sheath and for one other, a diagnosis of fibroxanthoma. One of the twelve tumors in the author's series occurred on the dorsal aspect of the wrist; this tumor eroded into the capitate and hamate bones. Another tumor occurred on the dorsal aspect of the distal phalanx of the middle finger. The remainder were located on the volar aspects of the fingers. There were nine females and three males in this series; recurrence was noted in only one case.

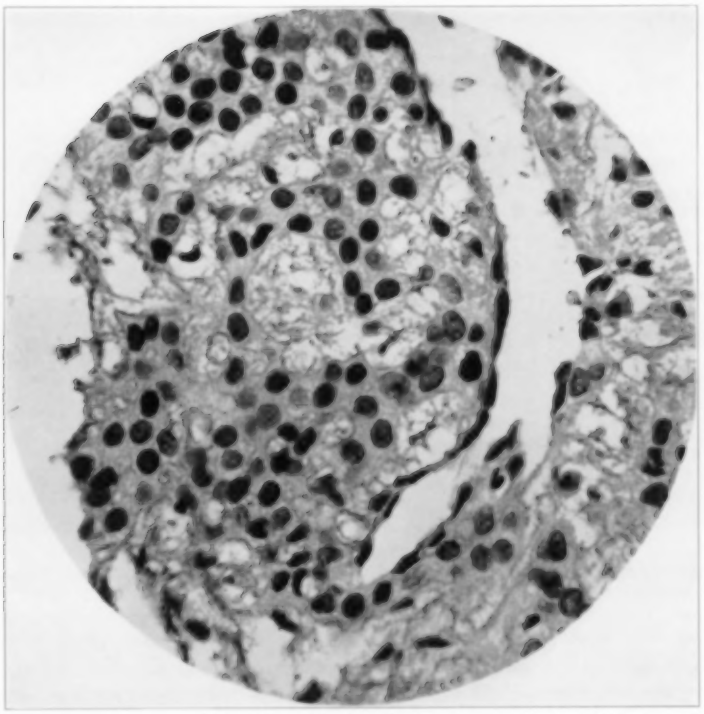

FIG. 13-F

High-power view (× 430) of a glomus tumor. Note the vessel and the glomus cells. The blood vessel is lined with endothelial cells, and the surrounding epithelioid cells have large, oval, darkly stained nuclei. The cytoplasm is faintly stained.

## GLOMUS TUMORS [35, 37, 41, 45, 52, 61, 62]

In the recent literature there have been a number of reports pertaining to glomus tumors. These reports have all emphasized that glomus tumors are difficult to diagnose and that they are relatively rare. The reports have also stressed that many times the diagnosis is not readily made despite the fact that pain of a usually severe nature and long duration is the predominant symptom.

Glomus tumors may be found in almost any part of the body; but the fingers, and especially the subungual areas of the fingers, are the most common locations. The tumor arises from the normal glomus, a structure which is present throughout the skin of the body and which, as a part of the vasomotor system, aids in the regulation of the body's heat. Trauma is thought to be a stimulating factor in some cases.

A pathological study of the gross specimen reveals that the glomus tumor is a small encapsulated growth with a diameter of from several millimeters to one centimeter. Its color is deep red or purple, and a microscopic study demonstrates that it contains many glomus-tumor cells and non-myelinated fibers. It is made up of blood vessels with thickened walls, the media in these vessels having been replaced by epithelial cells interspersed with smooth muscle cells and myelinated and non-myelinated nerve fibers. The glomus tumor, which occurs in persons of all ages, is said to be found in men more commonly than in women, and it is thought that it is subungual in about one-half of the cases. Its predominant symptom is pain which becomes worse when there are changes in the weather. The diagnosis may be based on the presence of this symptom and also on the presence of a

FIG. 14-A

FIG. 14-B

Two inclusion cysts that were found in the palm. Note that the white tumor is well encapsulated. Two more inclusion cysts were later found in the same palm.

bluish or cyanotic coloration under the fingernail. Occasionally erosion of the bone may be seen on the roentgenograms. The treatment consists in surgical removal, and the prognosis, following this treatment, is good. Multiple glomus tumors are rare but do occur (Figs. 13-A through 13-C).

In the author's series there were eight patients who had glomus tumors, two males and six females (interestingly enough, both males were physicians). The ages of these patients ranged from eighteen to seventy. Two of the tumors that were found were subungual, one was located in the palm, and the rest occurred in the soft tissues of the distal phalanges of the fingers. In two cases a definite history of previous trauma was obtained, and in all the patients pain was present in varying degrees. In one patient this pain was so severe that she was almost totally incapacitated. The relief of symptoms that occurred following removal of the tumor was remarkable. In another patient who was seen by the author but whose case is not included in this series, there was persistent pain in the distal phalanx. This patient was sent to the author after a diagnosis of glomus tumor had been made and surgical exploration had been performed by another physician. Further exploration was carried out by the author, and the growth was removed. It was thought by the author that the growth was a glomus tumor, but confirmation by microscopic examination could not be obtained. Following the surgery the pain disappeared and it has not recurred.

### EPIDERMOID CYSTS [21, 29, 75]

Epidermoid or inclusion cysts are frequently found on the hand, especially on the volar aspect of the fingers and palm. They usually occur in men who do a good deal of manual labor, such as carpenters, and it is thought that they either are due to trauma or are congenital in origin. According to the theory of trauma, the epithelial elements of the skin are implanted subcutaneously by the trauma, and as a result there develops a non-painful nodule which is hard and firmly fixed.

The tumor is composed of a cystic cavity which is filled with horny débris and cholesterol and which is surrounded by a wall of epithelium that somewhat resembles normal skin. Treatment consists in surgical removal of the tumor mass, the entire growth be-

FIG. 15

FIG. 16

Fig. 15: A pyogenic granuloma on the dorsal aspect of the hand. This tumor developed from a chronic infection which was due to an injury. Total excision of the tumor mass resulted in a cure.

Fig. 16: A foreign-body granuloma in the palm of the right hand. The patient was an employee in a gasoline station, and the tumor had developed following the injection of grease under high pressure. A previous attempt to remove the tumor had been made elsewhere, but this attempt had failed and the nodules had recurred. The author cleaned the entire involved area in the palm and also the dorsal aspect of the right long finger where further nodules had appeared. Subsequently the ring finger became involved and another operation was necessary. In the two years since the last operation was performed, there have been no new granulomata.

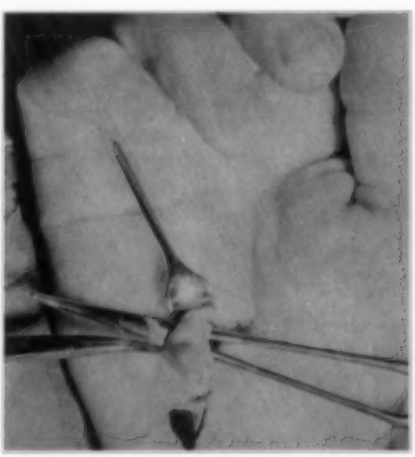

FIG. 17-A

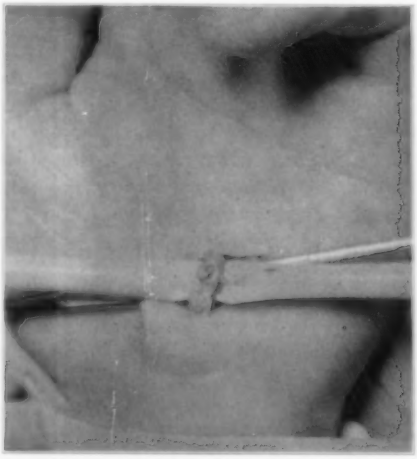

FIG. 17-B

Fig. 17-A: Traumatic aneurysm on the ulnar portion of the superficial volar arch of the right hand. This tumor had undergone thrombosis, and the symptoms were marked. It was originally thought that the neoplasm was a neuroma which involved the digital nerve of the little finger and of the ulnar side of the ring finger. At surgery, however, a diagnosis of aneurysm was made. Excision of the tumor resulted in relief of pain.

Fig. 17-B: In the patient described in Fig. 17-A, a second thrombosis occurred in the ulnar artery of the left palm. As soon as the patient began to complain of symptoms, surgery was performed. Immediate relief was obtained.

FIG. 18

FIG. 19-A

Fig. 18: Arteriovenous aneurysm involving the palm, a portion of the ring finger, and the index and middle fingers. The patient, a twenty-six-year-old housewife, had experienced extreme pain in the hand, especially during pregnancy. At the time of writing, surgery had not yet been performed.

Fig. 19-A: Hemangioma on the dorsal aspect of the left middle finger. This tumor was treated by excision, with primary closure of the wound. In the five years since the operation, there has been no recurrence.

ing dissected free from the surrounding area and removed. If all of the wall of the tumor is excised, the prognosis is good (Figs. 14-A and 14-B).

### PYOGENIC GRANULOMA [55]

Pyogenic granulomata are reddish mushroom-like growths that appear on the volar aspect of the fingers and on the palmar surface of the hand. In cases of these tumors there is usually a history of previous trauma or infection in the involved area, and bleeding from the involved area occurs readily, sometimes constituting the presenting complaint. The diagnosis is based on the gross appearance of the lesion and on the patient's previous history, and treatment consists in excision or cauterization; once the entire base of the tumor has been eradicated, the prognosis is good (Fig. 15).

### FOREIGN-BODY GRANULOMA [10, 51]

Foreign-body granulomata are caused by the accidental introduction of foreign bodies into the hand. Paraffin injected for cosmetic reasons or grease accidently injected under high pressure will also give rise to these foreign-body reactions (Fig. 16). After a foreign body has been introduced into the hand, it is surrounded by a mass of indolent granulation tissue with a dense fibrous-tissue capsule, as has been shown by microscopic studies. Within the resulting growth numerous foreign-body giant cells develop.

### TUMORS OF BLOOD VESSELS

#### *Traumatic Aneurysm* [60]

Aneurysms due to trauma usually arise from the superficial volar arch but may also arise from the deep volar arch. They may be the result of an injury to the artery which has been caused by a blunt blow or a sharp instrument.

FIG. 19-B

FIG. 19-C

Fig. 19-B: Hemangioma on the volar radial aspect of the wrist of a one-year-old child. The tumor was treated by total excision, with primary closure of the wound. No recurrence has been noted after two years.

Fig. 19-C: Large congenital hemangioma in a child only thirteen days old. Amputation was performed.

There are two types of traumatic aneurysms. One type is caused by repeated minor blows and is characterized by a uniform dilation of the vessels. In these lesions the walls of the vessels are thin but intact, and mural thrombi occur. The second type, the false aneurysm, is caused by a rupture of the wall of the vessel. The hematoma that results from this rupture is surrounded by connective tissue, a false sac being thus formed.

A diagnosis may be made by palpating the tumor and noting the resulting pulsation. If there has been thrombosis, pain will be present. In one patient treated by the author, there was pain and tenderness in the right palm for six months. The preoperative diagnosis in this case was neuroma, but subsequent exploration revealed that the patient had a thrombus of the ulnar artery (Fig. 17-A). According to Jackson [34], the occurrence of a thrombus in the ulnar artery is extremely rare; he has encountered only one case personally and has found only two reports in the literature. In the author's patient, however, the development of a thrombus in the right ulnar artery was later followed by a development of another thrombus in the left ulnar artery (Fig. 17-B). In this case, as in Jackson's case, resection of the involved segment resulted in relief of symptoms.

*Arteriovenous Aneurysm* [16, 18, 20, 30, 43, 66, 73]

Arteriovenous aneurysms are usually congenital in origin and may be noted in the newborn as well as in older patients. In young individuals an increase in the growth of the involved finger may occur. Aneurysms usually arise in the palm, on either the superficial or deep palmar arch, and they may involve more than one finger. They differ from aneurysms caused by trauma in that they contain multiple vascular communications.

The chief symptoms of arteriovenous aneurysms are enlargement of the finger, the presence of some pain, and the occurrence of pulsations. If the vascular communications are large, cynosis may be found at the finger tip (Fig. 18). The diagnosis may be made from the presence of local swelling and local elevation in temperature and from the occurrence of pulsations. Arteriography is helpful in locating the vascular communications but is not necessary as a diagnostic procedure. Cardiac changes are usually not noted.

FIG. 19-D

FIG. 19-E

Fig. 19-D: Large hemangioma in the palm of the left hand. Because of the diffuse swelling caused by this tumor, a preoperative diagnosis of lipoma was made.

Fig. 19-E: This large hemangioma was found at operation. The pathological report was hemangioma of the tendon sheath. In the four years since surgery was performed, there has been no recurrence.

In the treatment of these tumors, excision should be attempted before a decision is made to amputate. It has been stated that it is rarely possible to excise all of the fistulae.

The author has encountered two cases of tumors of this type. In one of these cases an operation was recently performed, some improvement being obtained as a result. The anteriovenous fistulae were excised first from the medial side of the involved (middle) finger and then from the lateral side. Subsequently pulsation and pain disappeared, but, in spite of the fact that a tendolysis had been performed at the second operation, the patient now has only limited flexion in this finger.

*Angiomata* [27, 60, 72]

Angiomata may be classified under four headings: angioblastic growths, telangiectatic growths, cavernous growths, and capillary growths. The first two types are perhaps of less consequence than the others, the first being very rare and the second usually being no more than a cosmetic blemish. If the latter are unsightly or if they begin to grow, they should be removed.

Capillary growths can be treated by coagulation, by excision, or by the application of carbon-dioxide snow. They may occur in association with areas of cavernous tissue, and when they do, destruction may occur in the surrounding tissue as a result of pressure. According to Mason [50], when these two types of tumor occur in combination, they may eventually take on the characteristics of arteriovenous aneurysms and may extend over large areas. For this reason, he feels they should be removed early.

Cavernous angiomata are composed of large vascular sinuses and may invade the entire hand. Although surgery can be performed, it is sometimes difficult to remove the entire tumor, and occasionally, after the operation, the skin may heal slowly and skin grafting may be necessary. During the operation, the slow release of the tourniquet to allow blood to enter the vessels may be an aid in the identification of the vessels. Ligation can be done before the cuff is completely deflated. Recurrence of the tumor after removal is possible (Figs. 19-A through 19-E).

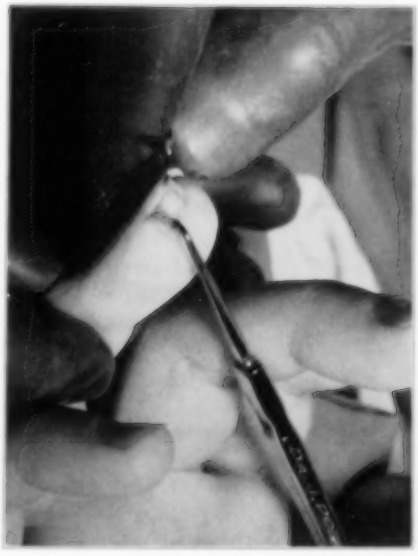

FIG. 20

FIG. 21-A

Fig. 20: An osteochondroma involving the distal phalanx of the left ring finger. Excision resulted in a cure, and three years after the operation the patient had a good functioning finger, free of pain.

Fig. 21-A: A chondrosarcoma in a colored male, sixty-eight years of age. In this case the entire involved finger, including the metacarpal, was removed. In the one year since the operation there has been no recurrence.

FIG. 21-B

FIG. 22

Fig. 21-B: Roentgenogram of hand shown in Fig. 21-A.

Fig. 22: A fibrosarcoma in the left index finger. The finger was amputated, and in the ensuing five years no metastasis has been noted.

### TUMORS OF THE PERIPHERAL NERVES [17, 25, 67]

Fibrillary neuroma is the name given to neuromata that result from the severance of a peripheral nerve. The chief symptoms of these tumors are pain and tenderness at the site of the growth and anaesthesia distal to the line of severence. If neuromata occur on an amputation stump which is painful, their excision, combined with the placement of the nerve ends in nearby subcutaneous tissue, often brings relief. The proximal end of the involved peripheral nerve is greatly enlarged, and a microscopic study will demonstrate all the elements of the nerve.

True fibrillary neuromata are rare. They have been described as "enlargements in excess of need of peripheral nerves" and, "when they involve the deeper nerves, they are sometimes associated with localized hypertrophy of a part (elephantiasis nervorum)" [32].

Tumors of the nerve sheath (neurilemoma) occur on the hand only occasionally, and when they do, arise on the flexor surface. These tumors are small, benign, and well encapsulated.

Other peripheral-nerve tumors which occur on the hand are the subepidermal types (the neurofibroma and the neurofibroma of von Recklinghausen). These neoplasms occur along the nerve trunks and involve the nerve. They sometimes recur, and they may lead to malignant degeneration. Neurogenous sarcomata also occur on the hand, arising from tumors of the nerve sheath. For these tumors, amputation may be necessary.

### BONE TUMORS [6, 12, 24, 26, 35, 44, 53, 57, 58, 59, 64]

The benign bone tumors that are encountered on the hand are cysts, chondromata, exostoses, xanthomata, giant-cell tumors, osteochondromata, and osteoid-osteomata. The malignant tumors that are encountered are osteogenic sarcomata, chondrosarcomata, and Ewing's tumors. Metastatic tumors are extremely rare.

The cause of bone cysts is not known. These tumors are found in the phalanges more often than in the metacarpals, and their symptoms are usually referable to a fracture which has occurred through the weakened involved bone. The epiphyses of the bone are not affected by the cyst. The diagnosis of these tumors is made by roentgenography, and the treatment consists in curettement of the cyst, sterilization of the cavity with phenol, and filling-in of the space with bone chips. Solitary cysts are of the osteitis fibrosa cystica type, the majority of these occurring in young adults.

Chondromata are frequently found on the hand, usually in the shaft of a metacarpal or phalanx. The cortex is not broken through by these tumors but may become so thin that bone-grafting is necessary. Other than frequent fractures of the involved bone, chondromata show no characteristic symptoms; and their treatment consists in curettage and cauterization with Zenker's solution or with 50 per cent zinc chloride. These tumors are benign, but if they are not entirely removed, they may recur.

Exostoses rarely occur on the hand, but when they do occur, they often arise near the joint as the secondary result of an injury. Subungual exostoses have also been reported. In this location, the tumor causes pain, especially if pressure is placed upon the nail. Treatment consists in total excision.

The xanthoma or giant-cell tumor occasionally occurs in the metacarpal. These tumors begin in the epiphyses but may eventually involve the entire bone. As seen on the roentgenogram, "the giant-cell tumor has a peculiar 'soap-bubble' appearance in that numerous trabeculae run through the tumor and divide it into many small translucent areas" [47]. The treatment is similar to that given for bone cysts and chondromata.

In rare instances osteochondromata have been found on the hand near the head of a metacarpal. These tumors may be seen on the roentgenograms and may produce local-pressure symptoms. Excision of the entire base of the tumor as well as of the growth itself lessens the possibility of its recurrence (Fig. 20).

Although osteoid osteoma of the hand has on the whole been rare, there have been some recent reports of its occurrence. In cases of this tumor pain and tenderness are revealed by a clinical examination, and a small osteolytic area may be noted in the cancellous bone. Surgical removal results in a cure.

Osteogenic sarcomata are also rare, although occasionally they are found in the metacarpals. In some cases of this tumor, trauma has been reported as an etiological factor, and in all cases pain has been noted. The diagnosis is made by roentgenography and biopsy, and the treatment consists in amputation.

In the author's series, a chondrosarcoma of the hand was encountered in a sixty-eight-year-old male. Chondrosarcoma usually occurs in older individuals, and its course is slow. It is thought to arise from mature cartilage, and amputation is the treatment of choice (Figs. 21-A and 21-B).

### FIBROSARCOMA [4, 5, 76]

Fibrosarcomata are thought to arise from connective-tissue elements or from benign tumors of fibrous-tissue origin. Their appearance may vary considerably, as has been shown by microscopic studies; and it sometimes happens that their clinical course is that of a benign tumor, while their microscopic picture is that of a malignant tumor.

Fibrosarcomata are quite large and are located in the superficial tissues more often than in the deep tissues. The diagnosis may be based on the fact that the tumor has been present for some time, and the best evidence of a malignant condition is local recurrence within a year of removal. Metastasis usually occurs by means of the blood stream, but extension to the epitrochlear or axillary nodes may occur by means of the lymph system.

The treatment usually consists in wide local excision. Amputation may also be done, however; and if the tumor is recurrent, amputation is a necessity. For high-grade malignant tumors, the prognosis is poor (Fig. 22).

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## DISCUSSION

Dr. Michael L. Mason, Chicago, Illinois: As Dr. Posch has stated, the carcinomata which arise from x-ray dermatitis metastasize very late and are, therefore, not highly malignant. The lateness of their metastasis is due to the presence of fibrosis of the subcutaneous tissue and corium, which blocks the lymphatic vessels and thereby tends to prevent early lymphatic spread. Once the barrier provided by the fibrosis has been passed, however, and once the bone and deep soft tissues have been invaded, the carcinoma spreads in the same highly malignant manner in which any other squamous-cell lesion spreads. This has been demonstrated by two recent experiences. Another factor which favors the late spread and the low invasive tendency of these carcinomata is the fact that 80 to 90 per cent of all carcinomata are of low-grade malignancy. As has just been mentioned, however, when a carcinomatous lesion does begin to spread, the nature of its malignancy changes.

The tiny synovial cysts which occur about the distal interphalangeal joints and about the base of the nail appear to arise from the deeper layer of the corium rather than from the joint capsule. These neoplasms tend to recur quickly after unsatisfactory attempts at their removal, and, in our experience, the only safe method of treatment is to excise them *in toto* along with the overlying skin and to cover the resulting defect with a graft.

The prognosis for the melanotic whitlow of Hutchinson is better than that for any other malignant melanoma. The accepted mode of treatment for this tumor is amputation of the digit, followed by dissection of the epitrochlear and axillary lymph nodes; the cure rate following this procedure is high. It is usually recommended that the amputation be performed first and then five or six weeks later the dissection be performed. If the operative approach used for carcinoma of the breast were to be adopted, however, the surgeon would commence with the lymph-node dissection and then, at the same operative session, would proceed downward to carry out the amputation. It would be interesting to know if this latter operation would be possible or feasible in cases of melanotic whitlow.

Dr. L. D. Howard, Jr., San Francisco, California: I feel that there are two distinct types of ganglia, the ordinary ganglia which occur on the dorsum of the carpus in younger individuals and the rheumatic ganglia which are found in older individuals. Before a ganglion is treated, it should be diagnosed according to its type. In my experience the use of compound F has not been beneficial in the treatment of ordinary ganglia but has been most helpful in the treatment of rheumatic ganglia.

Occasionally the pressure of a ganglion on the volar aspect of the wrist destroys the function of the deep branch of the ulnar nerve. It is unusual for a ganglion to damage the structures which surround it, however, and it is only because of the peculiar nature of its location in the wrist that it affects the ulnar nerve. I have personally seen one case in which damage to the nerve occurred, and Seddon of England has recently reported four cases.

The mucous cyst which occurs on the hand is an interesting lesion. It almost always occurs in persons past middle age, and it is almost always associated with mild or moderate degenerative arthritis. Although mucous cysts have been considered to be tumors of the skin, there is evidence that they actually may arise from any level, including the joint capsule and the extensor tendon. In one case which I encountered, there were multiple cysts and the degeneration was so extensive that, in three digits, the central slip of the extensor tendons had been destroyed where it crosses the distal joint; drop-finger deformity resulted.

A number of mucous cysts have been treated by immobilization and injections of compound F. The results of this treatment have been moderately good: in some instances the cysts have not recurred and in some instances they have (in a few cases follow-up was not obtained). If good results are not obtained by conservative means after one or two attempts have been made, there is certainly no objection to the performance of surgery. If surgery is done, the cyst should be excised and the resulting defect should be covered by a split-thickness skin graft.

Since 1949, five additional cases of carcinoma of the nail have been reported. The author who reported three of these cases has stressed that the early destruction of the distal phalanx which occurs as a result of the tumor, as is shown by roentgenograms, is important as a symptom upon which the diagnosis may be based.

X-ray and solar dermititis have previously been mentioned as etiological factors in the development of carcinomata. Another etiological factor is the keratoses which results from chronic arsenic poisoning, this poisoning being caused by the overuse of such products as skin lotions or gargles containing arsenic. When keratoses develop as the result of arsenic poisoning, they occur all over the body but are particularly pronounced on the palms and soles. In the latter areas, carcinomatous degeneration has been known to occur.

Metatastic carcinoma of the hand has been receiving more attention recently than it ever has before. This form of carcinoma usually occurs in the bones, especially in the distal phalanx of the thumb, and carcinoma of the lung is commonly the primary site.

Dr. Posch did not mention the tumor known as synovioma. This tumor does occur on the hand, although only rarely. When it occurs, it usually arises near a joint and extends by infiltration into the adjacent soft tissues; it seldom invades the joint itself.

We have not seen many aneurysms in our practice; most of those we have seen were of the traumatic type, having apparently developed as the secondary result of a confined hematoma. It is our impression that non-congenital arteriovenous communications are extremely rare.

Dr. Leo Mayer, New York, N. Y.: There are only one or two points which I wish to add to Dr. Posch's very inclusive paper. One of these points concerns the rate of recurrence of xanthomata. Dr. Posch has given this rate as 10 per cent, but I believe it is generally considered to be somewhat higher. In one case which came to my attention, the patient had been operated upon three times for an xanthoma at the base of the thumb. A fourth operation upon this patient demonstrated that the tumor had invaded the metacarpal bone to a depth of about half an inch, and it was only after the bone had been thoroughly curetted that a cure was achieved.

In cases of the tumors which occur in the metacarpals and which resemble sarcomata, it is recommended that a conservative approach be tried before amputation is performed. About twenty years ago an Italian girl came to the clinic with a tumor of the fourth metacarpal which appeared to be extremely malignant. Amputation was strongly recommended, but I decided to try a conservative operation and excised the metacarpal, replacing it with a bone graft. After the operation, the neoplasm was found to be not a true sarcoma but a very unusual type of pseudosarcoma. The patient has been followed for twenty years; she is now married and perfectly well, and there has been no recurrence of the tumor.

The type of pseudosarcoma found in this case has been described in the Scandinavian literature. It can be recognized if it is carefully observed, and it does not necessarily require amputation, even if the roentgenographic picture is that of a very malignant tumor. Amputation may eventually be performed, of course, but in most cases a conservative operation should be tried first.

Dr. Posch (closing): In regard to the treatment of melanomata, which Dr. Mason discussed, we recommend that amputation be performed first and that two weeks later axillary dissection be done.

In cases of carcinomata of the hand in which there is no evidence of metatasis, there are two follow-up approaches which may be used. The patient may simply be observed periodically to make sure there is no recurrence of the tumor, or, six weeks after the performance of the amputation, prophylactic dissection of the axillary nodes may be done. For some carcinomata of the extremities, the approach used for carcinomata of the breast might be excellent, and I know this approach has been used satisfactorily on inguinal tumors which

*(Continued on page 562)*

# Meniscus Injuries of the Temporomandibular Joint *

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Injuries of the meniscus of the temporomandibular joint are undoubtedly more common than is ordinarily supposed. However, they frequently do not come to the attention of the orthopaedic surgeon because the patient consults either a dentist or otolaryngologist for supposed trouble with the teeth or ear. If these structures are found unoffending, the patient often has persistence of jaw symptoms for which no definitive treatment is offered. We are fortunate in Rhode Island in that our dentists, otolaryngologists, and orthopaedic surgeons are jointly aware of the problem. Cases of this injury are being encountered with increasing frequency.

This presentation comprises a clinical study of forty-four patients operated upon for injuries to the meniscus of the temporomandibular joint. The operations were performed between 1948 and 1955.

Annandale reported the surgical repair of a torn meniscus of the temporomandibular joint in 1887. Lanz, in 1909, was the first to describe excision of the meniscus as a means of treatment of the condition. He operated on two young women who suffered pain and snapping of the temporomandibular joint on opening the mouth and he reported good results in both cases. Meniscus (articular disc) extirpation has been increasingly employed and has been recommended by a number of authors.[3, 4, 6, 8, 9, 10, 13]

## FUNCTIONAL ANATOMY

The temporomandibular joint although commonly described simply as a hinge joint, is a complex and highly specialized structure. It is divided by an articular disc (meniscus) into two completely separate joints which may be regarded as functionally distinct (Fig. 1). The upper joint, between the temporal bone and articular disc, functions principally in gliding movements, while the lower joint, between the articular disc and mandibular condyle, functions as a true hinge joint. Both the gliding and hinge actions of these joints are essential to the normal opening and closing of the mouth (Fig. 2), for it is because of these actions that the muscles can carry out the three principal movements of the jaw: (1) forward-rearward movement, (2) opening-closing movement, and (3) lateral movement.

The joint capsule is rather thin but is strengthened laterally by a thickened ligament, the temporomandibular ligament. The capsule between the temporal bone and disc is quite loose, allowing the extensive gliding movements of the upper joint to take place. Between the articular disc and mandibular condyle the capsule is taut.

The articular surfaces of the temporal bone and mandibular condyle are unusual in that they are covered by fibrocartilage rather than by hyaline cartilage. These bone surfaces are not symmetrical, and the articular disc, which is elastic and adaptable, serves to adjust the incongruities between them.

The articular disc is composed of dense fibrous tissue. In his extensive anatomical studies, Wakeley [14] found that, contrary to the usual textbook description, the disc is thickest in its central and anterior portions. Between these two thickenings there is a distinct depression, and posteriorly, where it passes down over the back of the condyle to fuse with the capsule, the disc is thin.

* Read before the Section on Orthopedic Surgery at the Annual Meeting of The American Medical Association, Atlantic City, New Jersey, June 9, 1955.

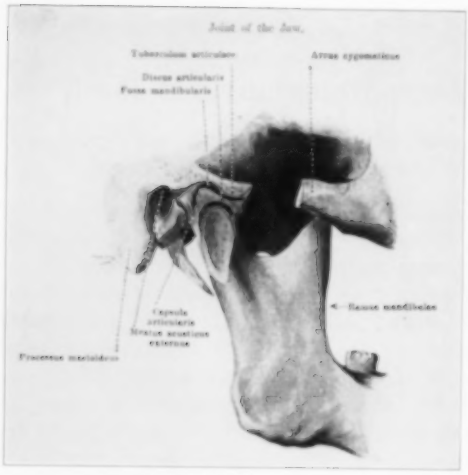


FIG. 1

FIG. 2

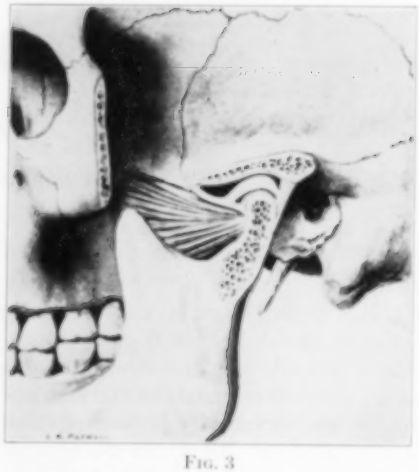

FIG. 3

Fig. 1: The articular disc (meniscus) divides the temporomandibular joint into two separate "joints". (Reproduced by permission from Werner Spalteholz: Hand Atlas of Human Anatomy. Ed. 5, p. 170. Philadelphia, J. B. Lippincott Co., n. d.)

Fig. 2: Positions of the jaw when the mouth is in the closed and opened (pale outline) positions. Note that the meniscus and mandibular condyle move forward when the mouth is opened. (Reproduced by permission from Spalteholz: Hand Atlas of Human Anatomy. Ed. 5, p. 173. Philadelphia, J. B. Lippincott Co., n. d.)

Fig. 3: The external pterygoid inserts into the anterior capsule and the articular disc and pulls the latter forward when the mouth is opened. (Reproduced by permission from Cecil Wakeley: The Mandibular Joint. Ann. Roy. Coll. Surgeons, 2: 120, 1948.)

The external pterygoid muscle inserts into the anterior capsule and anterior portion of the articular disc (Fig. 3) and causes the forward movement of the disc which is essential to the routine opening of the jaw. Benninghoff has regarded the disc as the tendon plate of the upper part of the external pterygoid.

A sudden or forceful contraction of the external pterygoid muscle can detach the thin posterior attachment which joins the articular disc to the capsule. The muscle fibers then draw the entire meniscus forward, lodging it anterior to the mandibular condyle where it acts as a mechanical block, preventing the normal gliding-and-hinge action of the temporomandibular joint.

## ETIOLOGY

1. As regards the possibility of *heredity* being a factor, very little is known.

2. *Inflammatory conditions*, such as influenza or rheumatoid arthritis, may produce pain, crepitation, and tenderness over the temporomandibular joint. Inflammatory conditions are uncommon, however, and almost always present other systemic involvements.

3. A history of *wide opening of the mouth*, such as occurs in yawning or chewing or such as is required in a dentist's office, is fairly frequent in meniscus injuries of the temporomandibular joint. About one-third of our patients related that the initial symptoms had developed following wide opening of the mouth. Many observers are agreed, however,

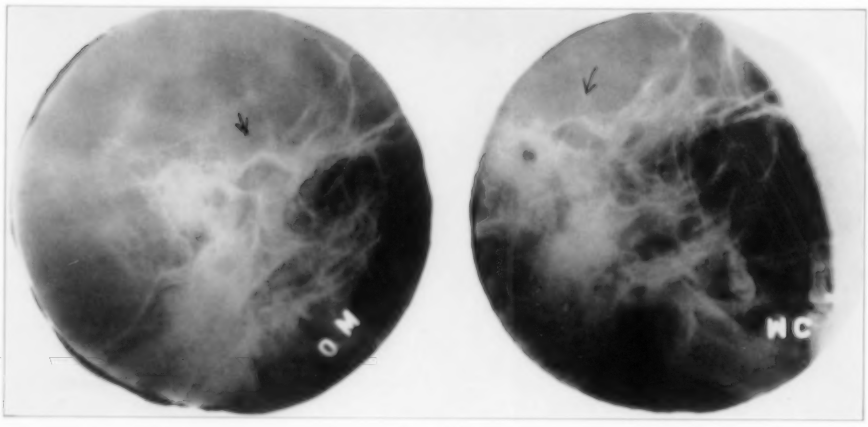

FIG. 4-A

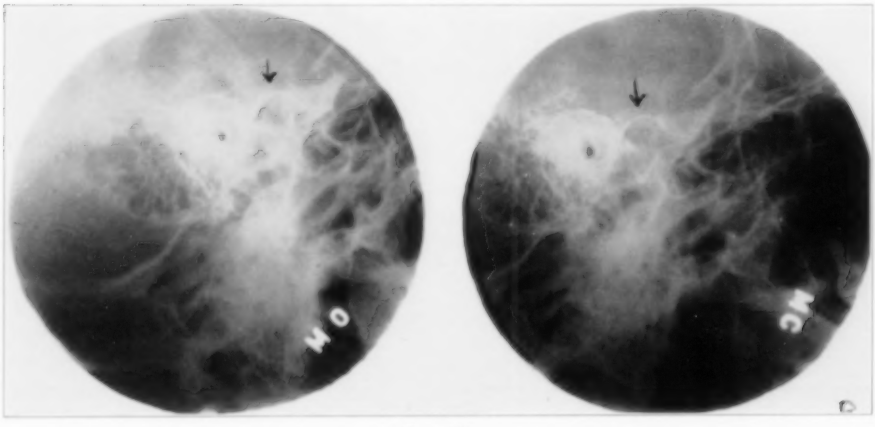

FIG. 4-B

Figs. 4-A and 4-B: Roentgenograms of the jaw of a female, forty-one years of age, with a meniscus injury of the right temporomandibular joint. When the mouth is open, the left mandibular condyle moves forward (Fig. 4-A), but the right condyle is blocked (Fig. 4-B).

that the trauma from this action merely precipitates the symptoms but is not the underlying cause.

4. *Direct trauma* to the jaw, by a blow or fall, was cited by three patients in our series.

5. *Malocclusion* (faulty bite) is considered by most investigators to be the predominant cause of injury to the meniscus of the temporomandibular joints.

Fifty per cent of our patients were unable to offer any information regarding the cause of their difficulty.

## SYMPTOMS AND CLINICAL FINDINGS

Boman distinguishes between *local* and *peripheral* symptoms:

1. *Locally*, pain, snapping, and crepitation are common. Locking of the jaw, either transient or prolonged, is also common. This locking almost invariably occurs when the mouth is closed, as contrasted with dislocation of the jaw which occurs when the mouth is wide open. One of our patients, a fifty-two-year old female, was compelled to feed herself through a gap between the molar teeth for one month, being unable to open her clenched jaws. This condition was relieved by excision of the anteriorly displaced articular disc.

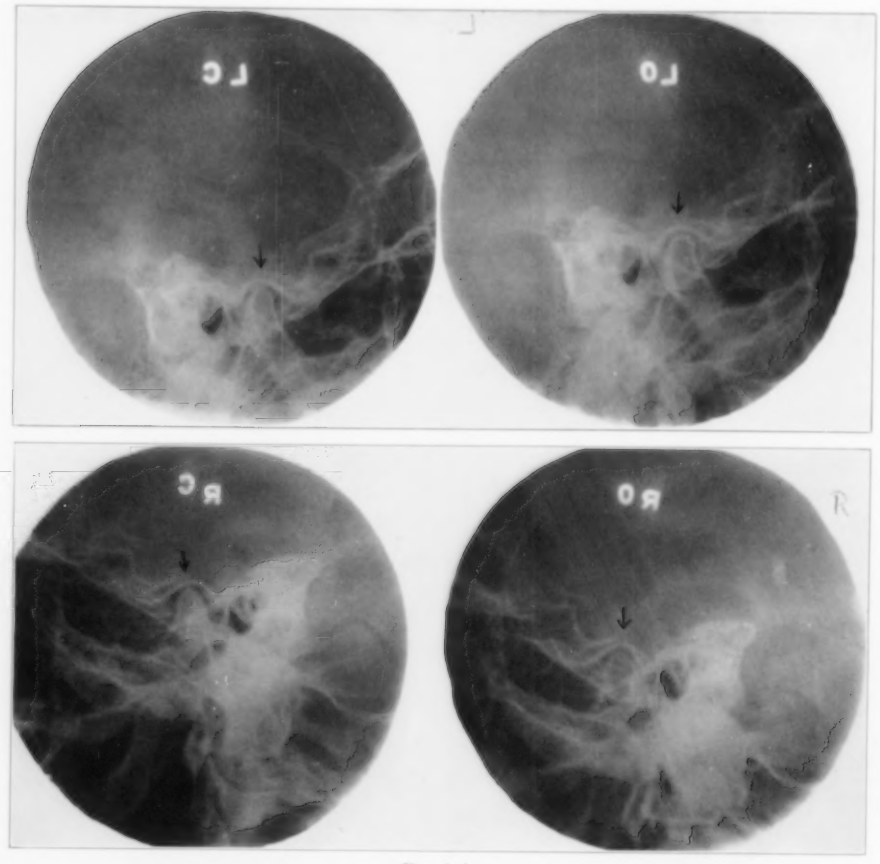


FIG. 5-A

Roentgenograms of the jaw of a female, thirty-seven years old, with a severe injury of the left temporomandibular meniscus. These views, made in the closed-and-opened-mouth positions, show that on both sides movement of the mandibular condyle was greatly restricted in the open-mouth position.

2. Not infrequently patients complain of such peripheral symptoms as dull pain within or about the ear, tinnitus, pain referred to the top of the head or side of the jaw, burning or prickling of the tongue, and the presence of a metallic taste in the mouth.

Costen attempted to explain this symptom complex, which includes impaired hearing, by postulating that mechanical pressure is placed on the eustachian tube and chorda tympani nerve by the mandibular condyle. This explanation has been disproved by detailed anatomical studies, however, and it is most probable that the peripheral symptoms are due to referred reflex pathways which are the result of irritation of the auriculotemporal and trigeminal nerve fibers in the capsule of the temporomandibular joint.

An examination usually reveals several, and frequently all, of the following symptoms:

1. Tenderness directly over the involved temporomandibular joint.

2. Limited opening of the mouth. Normally the mouth can be opened so that there is a space of one and one-half inches between the tips of the incisor teeth. In patients with a meniscus injury this space is often restricted to one inch or less.

3. Snapping and crepitation in the affected temporomandibular joint are frequently felt by the patient and occasionally are even heard by others. These symptoms may occur during opening or closing of the mouth or during both.

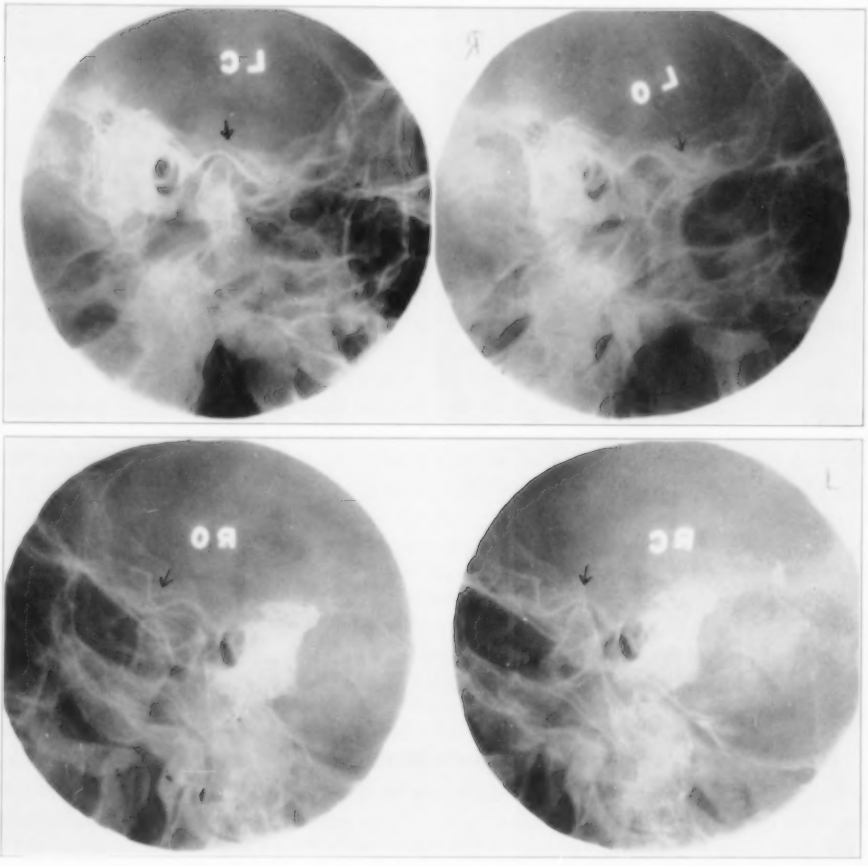

FIG. 5-B

Roentgenograms made two months after excision of the left meniscus. Both condyles move forward freely when the mouth is opened.

4. Deviation of the jaw toward the involved side occurs in many instances, this deviation being due to impairment of the gliding motion of the joint with resultant shift of the mandible.

Routine x-ray studies of both temporomandibular joints, with the mouth in both the closed and widely opened positions, should be made for purposes of comparison.

One significant finding that has been observed roentgenographically is that in most cases there is a definite restriction of the forward excursion of the mandibular condyle on the involved side of the jaw (Figs. 4-A and 4-B). In patients with severe involvement, this restriction often occurs on both sides of the jaw (Figs. 5-A and 5-B).

The roentgenograms give valuable information regarding the bony status of the jaw and provide evidence by means of which a diagnosis of arthritic changes, bone tumor, or local deformity may be ruled out.

## ANALYSIS OF CASES

This report presents the cases of forty-four patients who were operated upon for an injury to the meniscus of the temporomandibular joint.

Total extirpation of the meniscus was carried out in each instance, and in one case, a markedly deformed mandibular condyle was also excised.

*Sex:* Of the forty-four patients, forty were females—approximately 90 per cent. This percentage compares rather closely with the percentage for Boman's series, in which 86 per cent of the fifty-eight patients were women. An anatomical study of a series of skulls showed that the temporal tubercle is lower in women than it is in men, and that it is especially low in young women. No definite conclusion can be drawn from this finding.

*Age:* In our series, the age range extended from sixteen to fifty-six years and 81 per cent of the patients were under forty. In Boman's series 88 per cent of the patients were under forty.

*Side:* There was no significant difference in the number of the right and left sides involved.

*Duration of symptoms prior to surgery:* The average duration of symptoms prior to surgery was eighteen months. In ten patients there were persistent symptoms for more than two years and in one the symptoms were present for more than ten years. In none of these cases had relief been obtained by conservative measures. In one case the jaw was completely locked with the teeth tightly clenched for ten days, the ostensible cause of this locking having been a hearty yawn. The patient subsisted on coffee sipped through clenched teeth and surgery was considered urgent. In the operation the meniscus was found firmly wedged against the anterior portion of the condyle; it was removed and recovery followed.

*Days in hospital:* The average stay was four or five days, although ten patients were discharged on the second day after the operation.

*Anaesthesia:* All the operations were performed with the patient under intratracheal anaesthesia, this type of anaesthesia obviating the placement of any cumbersome apparatus on the face and jaw. The tube was inserted through the nose in order to allow for free jaw motions during the operation, an important factor, as will be explained in the section on surgical technique.

## TREATMENT

A patient with the symptoms of an injury to the temporomandibular-joint meniscus should be treated first by conservative means. These consist in rest for the jaw, avoidance of all hard, chewy foods, application of heat locally, and sedation. The patient should be cautioned against yawning widely. In the authors' series, a number of patients were given intra-articular injections of hydrocortone solution (one-half cubic centimeter); the response to this treatment was good.

Most of the patients in the authors' series had previously been given conservative treatment, usually by a dentist, and had been referred to the authors because they had failed to respond to this treatment. Twenty-five patients were treated conservatively by the authors themselves. Of these patients twelve came to surgery; the others recovered satisfactorily without operation.

Each patient in the authors' series was referred to a dentist to see if bite correction was necessary. By bite correction is meant adjustment of the apposition of the teeth. To achieve this adjustment the dentist either files down the high points of the teeth or inserts a simple prosthesis to separate slightly the rows of teeth, thus reducing the pressure on the temporomandibular-joint meniscus. Malocclusion is a major factor in the development of a meniscus injury, as has been explained previously, and a significant number of patients with this injury, especially those treated in the early active stages of the disability, will make an uneventful recovery if good apposition is obtained by conservative management. In the authors' series, each patient was referred back to the dentist following surgery for a check on the apposition of the teeth; in a few cases further bite correction was necessary.

If the patient has a locked jaw or if he has a history of pain and long-standing or recurrent limitation of jaw movement (these symptoms not responding to the conservative measures described above), excision of the damaged meniscus is definitely indicated.

FIG. 6-A

FIG. 6-B

Fig. 6-A: The meniscus has been removed and is shown lying on the gauze. The mandibular condyle may be seen in the wound.

Fig. 6-B: When an angulated, vertical incision is used, one avoids the danger of cutting any of the branches of the facial nerve. *A*, auriculotemporal nerve; *F*, facial nerve. (Reproduced by permission from K. H. Thoma: Oral Surgery. Vol. II, p. 902. St. Louis, The C. V. Mosby Co., 1952.)

## THE OPERATION

From a surgical point of view, the anatomy of the temporomandibular joint is of great significance, the close proximity of the more vital structures being the most important consideration.

Posteriorly, the superficial temporal artery and the auriculotemporal nerve course vertically. The facial nerve and upper portion of the parotid gland lie inferiorly, the facial-nerve motor branches of the forehead and orbicularis oculi lie anteriorly, and the base of the zygoma bounds the joint superiorly. Add to these anatomical considerations the fact that the cheek is very vascular, and it will be realized that the approach must be carried out with great care.

The side of the face on which the operation is to be performed is shaved, the area to be shaved extending forward and downward from the level of the top of the ear. It is unnecessary to shave widely or to produce a disturbing partial baldness. The ear is left exposed in the operative field, a small sterile pledget being placed in the external canal; this provides a means of surgical orientation (Fig. 6-A).

In their first operations the authors used an L-shaped incision [5]. Later, for a period of six years, they used a simple transverse incision. This incision was about one and one-quarter inches long and was made directly over the temporomandibular joint along the lower border of the zygoma. In a large percentage of the cases in which this incision was used, paresis of the forehead muscles on the involved side occurred due to the mechanical retraction of the motor-nerve branches. This reaction was transient, disappearing in every instance within three to six weeks; while it was present, it was disturbing cosmetically.

Last year the authors changed to the Thoma incision (Fig. 6-B), which runs vertically close to the margin of the ear and then extends obliquely upward and forward for a short distance. In order that damage to the facial nerve may be avoided, care must be taken that this incision stops one-quarter of an inch above the lower lobe of the ear. Following the making of the incision, the deeper tissues are dissected forward bluntly *en masse* until the zygoma is reached. The facial-nerve motor branches to the forehead and orbicularis oculi are retracted forward within the soft-tissue flap and are thus not subjected to injury. The authors have been very much impressed by the Thoma incision; among other advantages which have resulted from its use is the fact that the transient forehead-muscle paresis has been largely eliminated.

The repeated instillation of epinephrine solution (1:1,000) into the wound during the operation is of great value in controlling the bleeding. The use of a suction tip is also very helpful in keeping the operative field clear.

The temporomandibular joint can be identified easily by means of palpation if the anaesthetist moves the jaw up and down under the drapes. The joint capsule is incised transversely along the lower border of the zygoma and is then stripped downward by means of a sharp periosteal elevator. The articular disc is thus brought into view.

The disc is grasped laterally with a small clamp and is dissected free laterally and anteriorly. Since the space between the mandibular condyle and the temporal fossa is exceedingly narrow, it is difficult to insert a cutting instrument into the joint space, a step which is necessary in order to detach the medial border of the disc. One author[5] has advised passing a wire through the lower mandible to distract the temporomandibular joint, but we consider this procedure inadvisable and unnecessary.

In one of the authors' earlier operations, the anaesthetist inserted his padded fingers behind the lower incisor teeth and pulled forward strongly on the mandible. This maneuver pulled the mandibular condyle well forward, allowing clear access to the meniscus. It was then relatively simple to excise the remaining posterior and medial attachments and to remove the meniscus (Fig. 6-A). This procedure is now considered very valuable and is used regularly, the draping being arranged to allow the anaesthetist's hand to reach freely into the mouth as needed.

Following removal of the meniscus, the joint space should be inspected very carefully in order that any small remnants of disc material may be picked up. The joint space is then packed with adrenalin-soaked pledgets for several minutes, a procedure which controls the bleeding very well.

In closure, the capsule is repaired with several interrupted thin chromic sutures, the subcutaneous tissues being approximated and the skin being closed with No. 00000 dermalon sutures. A small gauze pressure dressing is applied to the wound with elastoplast strapping. No large bulky immobilizing dressings are required after the operation, for the masseter muscle acts as a very effective internal splint for the joint.

## OPERATIVE FINDINGS

The most common finding has been a slight-to-marked forward displacement of the meniscus in relation to the mandibular condyle, the posterior and occasionally the lateral attachments of the meniscus being torn. In most instances, this displacement has mechanically blocked forward motion of the condyle. In several cases, the undersurface of the disc presented rough ragged fringes, and in one case there was a large transverse tear through the middle of the disc. Frequently microscopic examination revealed round-cell infiltration and degeneration of the fibrous tissue; in some instances, however, it showed nothing of note.

## POSTOPERATIVE CARE

The day following the operation, the patient is allowed to eat soft food and to walk. The skin sutures are removed on the second or third day after the operation in order that scar formation may be minimized. The patient is then ready for discharge from the hospital (Fig. 7). An icebag is used for any transient local swelling.

In the authors' series no wound infections have occurred to date, and the resultant scars in the patients' hairlines are inconspicuous (Fig. 8). Transient hyperaesthesia of the cheek occasionally occurred, disappearing after a few weeks.

It is essential that the patient return to the dentist after the operation for further bite adjustment, and the patients are encouraged to carry out early mouth-opening exercises. In the month following the operation crepitation in the joint operated upon is occasionally noted, but this crepitation is without any particular symptoms. Some patients

FIG. 7

FIG. 8

Fig. 7: Left: the range of mouth-opening three days after the operation. Right: the Thoma incision was used in this case.

Fig. 8: The postoperative scar is inconspicuous.

Fig. 9: Free, painless range of mouth-opening five years after excision of the right meniscus.

FIG. 9

have a slight residual lateral deviation of the jaw toward the side operated upon, this deviation occurring because of a defective gliding movement on this side; the gliding movement is not symptomatic.

From the clinical standpoint, all of the patients in the authors' series stated that they were definitely improved after the operation and could chew all kinds of food without trouble, if their dental status permitted. Both the operative and non-operative sides of the jaw could be used for mastication without trouble.

## COMMENT

It is realized that in this operation a compound joint is converted into a simple joint with articular surfaces which do not fit one another. During the weeks immediately following the operation, the temporomandibular joint functions primarily as a rotatory joint. This function undoubtedly produces stress on the joint cartilage, which may account for the occasional asymptomatic crepitations which are noted for a month or two after operation. The joint appears to accommodate itself relatively soon, however, and gradually a gliding motion develops, this motion combining well with the rotatory movements of the discless joint. This joint can execute all the movements required for the intake and chewing of food (Fig. 9). As Boman states, the temporomandibular joint is a type of joint in which the movements are directed, not by the articular surfaces, but by the muscles.

The patients in this series have been called back periodically for re-examination and x-ray studies. Thus far, a five-year follow-up has not demonstrated any changes in the involved joint (Figs. 10-A and 10-B), but it is, of course, possible that a more extended follow-up will reveal such changes.

## CONCLUSIONS

Injuries to the meniscus of the temporomandibular joint are more common than is ordinarily supposed. The primary treatment of such an injury should be conservative in nature, including careful evaluation of the injury and correction of the patient's bite by a dentist. If a conservative regimen of therapy fails to produce the desired results, then meniscectomy of the temporomandibular joint is indicated.

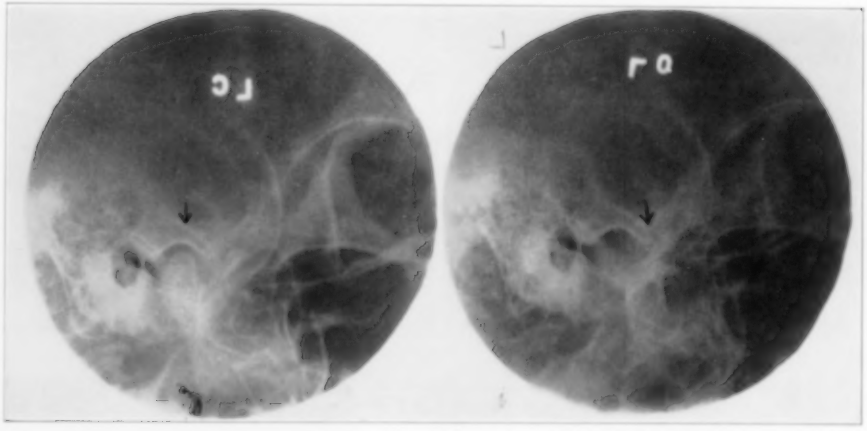

FIG. 10-A

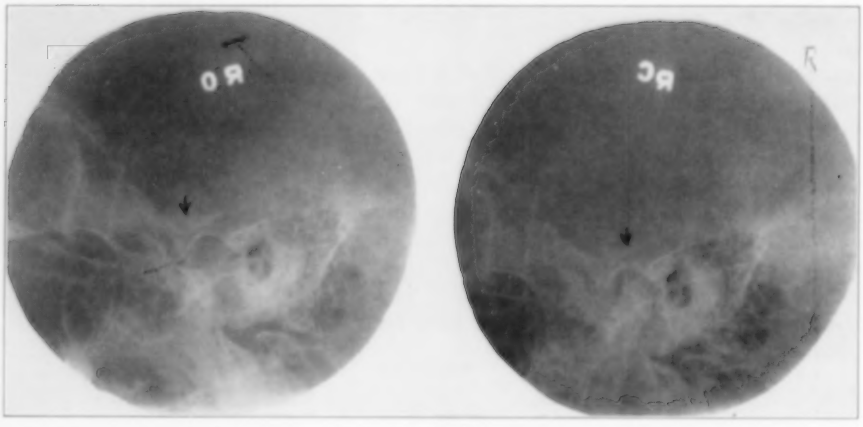

FIG. 10-B

Figs. 10-A and 10-B: Roentgenograms made five years after incision of the right meniscus. There is no evidence of bone abnormality and the motion of the mandibular condyle is unrestricted.

A series of forty-four cases in which operations were performed is presented, with a discussion of the operative technique and postoperative care. Good results may be anticipated from surgical treatment.

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## DISCUSSION

Dr. David M. Bosworth, New York, N. Y.: Although the population of Providence is less dense than that of New York City, the authors have operated upon forty-four patients in the last eight years, whereas we have seen only an occasional patient. This discrepancy is explained partly by the liaison which exists between dentists and orthopaedists in Rhode Island, but more important is the fact that by their skill the authors have converted the operation into a minor procedure. When faced with a choice between continued annoyance and mild postoperative discomfort followed by recovery, most patients and their advisors select surgery. Few of the authors' patients *demanded* surgical relief, but in my opinion use of this approach was justified in every instance.

The operation is simple and safe only in the hands of the experienced surgeon, and the reader should not be lulled into a sense of blasé confidence by the simplicity of the authors' presentation. It has been suggested that a surgeon should perform an anatomical dissection before proceeding with his first operation and it might be wise if he also watched one or two operations before attempting the procedure.

The amount of bleeding which sometimes occurs, even when no major vessel has been lacerated, is surprising: and on occasion we have had to pack a wound with gelfoam to stop the welling-up of blood. We have not tried the epinephrine instillation and suction visualization suggested by the authors.

Traction paresis of the branches of the facial nerve is probably unavoidable. It occurred in our cases but resulted in no ill-effects. Laceration of a facial nerve or even of a branch of this nerve might, of course, cause disfigurement, resulting perhaps in a demand for legal retribution.

In cases in which resection of the condyle of the mandible is necessary because of incongruity of the surfaces or because of fibrous ankylosis, the surgical problems are great. It may be essential to resect the posterior arch of the zygoma in order to uncover the neck of the condyle and, frequently, the jaw cannot be drawn forward, as it can be in cases in which only simple excision of the interarticular disc is necessary. Malocclusion does not seem much of a problem following simple disc removal, but following resection of one or both condyles it is a definite problem.

If there is evidence that the temporomandibular-joint injury may require surgery, preoperative adjustment of the bite would not seem wise. Adjustment of the bite after the operation is frequently necessary in any case, and it would not seem logical to make this adjustment twice, for the procedure requires grinding and shortening of the teeth.

While locking of the jaw when the mouth is closed is usually due to a pathological condition of the disc and locking of the jaw when the mouth is open is usually due to dislocation, the possibility that a fixed anterior dislocation of the condyle may be due to laceration of the meniscus cannot be ruled out. In such case the roentgenograms and operative findings must be considered before a final decision is made. Unless there are clear indications for condylectomy, this procedure should be avoided, and whenever possible, only the disc should be removed.

Dr. Edward L. Compere, Chicago, Illinois: The chewing of anything that requires a great deal of continuous masticating exercises not only the masseter but also the pterygoid muscle. As has been shown by the authors, the superior or upper head of the external pterygoid muscle inserts into the anterior rim of the meniscus or articular disc. The condyle moves forward when the mouth is opened and moves back to a resting position when the mouth is closed. The meniscus moves forward with the condyle, this forward movement occurring not because the disc is attached to the condyle, which it is not, but because it is pulled forward by the contracting external pterygoid muscle. The disc has no posterior muscular attachment, its posterior medial and lateral attachments being merely capsular.

When the disc moves forward with the condyle, the posterior capsular attachments are stretched. If the patient is accustomed to chewing vigorously, the external pterygoid muscle, as well as the masseter, becomes markedly hypertrophied, and being over-strong and over-active gradually stretches the capsular attachments until they are lax and loose even when the disc has been pulled forward. As a result of this relaxation of the capsular attachments and of the accompanying hypermotility of the condyle, the disc may not move back when the condyle returns to a resting position but instead may remain partially subluxated in front of the condyle.

In some instances, the posterior capsule attachments to the disc may be partially torn, as the authors have described. These tears may result in complete dislocation of the disc in front of the condyle, and in turn this dislocation may block the movement of the condyle when the patient attempts to open the mouth. In my own series, I have seen only one case in which the mouth could not be opened. In this case there was fibrosis and fixation of the lower jaw with the mouth locked shut.

The injuries in most of my cases were similar to those described by Roger G. Gerry and Robert L. Rowan; there was hypermotility of the condyle and stretching of the posterior capsular attachments with resulting failure of the meniscus to move back to its normal resting position. When the jaw was opened, there would be a click as the disc slipped back into the articular portion of the condyle as the latter started to move forward.

The patients in my series made a good recovery when they understood that prolonged chewing was the cause of their difficulty and discontinued this practice

## FORTY YEARS AGO

Dr. E. G. Brackett was in England in 1918. On this occasion, he and Sir Robert Jones were paying an official visit to Holymoor, Naughton Dunn's Hospital (2nd Birmingham War Hospital, Northfield). The snapshot comes to us through the kindness of Dr. Ralph G. Carothers, Cincinnati, Ohio.

# A Preliminary Study of Selective Plantar-Muscle Denervation for Pes Cavus *

BY GEORGE J. GARCEAU, M.D., AND MALCOLM A. BRAHMS, M.D., INDIANAPOLIS, INDIANA

*From the Orthopaedic Department of the James Whitcomb Riley Memorial Hospital, Indiana University Medical Center, Indianapolis*

Pes cavus or claw-foot occurs in association with some neuromuscular disturbance causing muscle imbalance. The deformity is often progressive and is usually difficult to correct. In this paper the authors present a preliminary review of their experience with selective plantar-muscle denervation as a method of treatment for pes cavus or for pes cavo-adductus.

In the past, the authors have used various surgical procedures for the correction of cavus and cavo-adductus deformities. In many instances the results of these procedures have been acceptable, often despite the fact that the resulting foot has been wide and short and has, therefore, been difficult to fit with a shoe. In other instances, the cavus deformity has not been corrected. The surgical methods employed by the authors have included fasciotomy, tenotomy, tendon transposition, reconstruction of the tarsal bones, and arthrodesis of the interphalangeal joints. Combinations of these procedures have also been used.

In 1952, the senior author began a study of the small muscles of the foot. From this study, he concluded that four of these muscles, acting when the muscle balance in the leg has been disturbed, are the principal deforming factors in pes cavus. The four deforming muscles are the abductor hallucis, the flexor digitorum brevis, the flexor hallucis brevis, and the quadratus plantae. It is generally recognized that there is no single cause of cavus deformities, which may occur in association with such conditions as infantile paralysis, spina bifida with neurological abnormalities, myelodysplasia, Freidreich's ataxia, Levy-Rossy syndrome, arthrogryposis, talipes equinovarus, and cerebral palsy.

In 1938, Michael Burman reported a case of spastic flexion deformity of the toes. He was able to obtain a satisfactory correction of this deformity by sectioning the motor branches of the lateral plantar nerve in the region of the fourth interosseous space. Adolph Schmier, in 1945, reported sectioning of the motor branches of the lateral and medial plantar nerves in a patient with a spastic calcaneocavus deformity. No other references to procedures of this type have been found.

Duchenne attributed pes cavus to a weakness of the muscles supplied by the lateral plantar nerve. The authors agree with this opinion in part but also feel that the deformity may be produced by an imbalance among the plantar muscles. In 1921, after using the Duchenne principle of electro-stimulation in a study of the foot and its kinetics, Levick reported that the short flexors (and especially the flexor digitorum brevis) have a strong "arch-raising action". Hans Debrunner, in 1920, concluded that the abductor hallucis was the largest muscle on the plantar side of the foot capable of increasing the arch. He mentioned two factors as contributing to the strong "arch-raising action" of this muscle; one was the tendency of the muscle to shorten the distance between its origin and insertion, and the other and principal factor was the advantageous location of its origin.

* Read at the Annual Meeting of The American Orthopaedic Association, White Sulphur Springs, West Virginia, June 20, 1955.

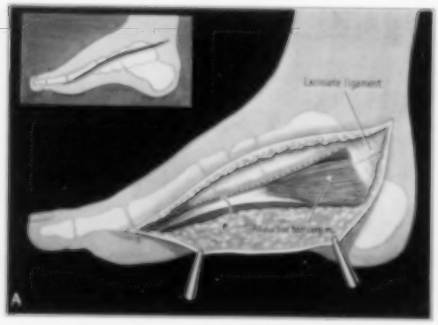


FIG. 1-A

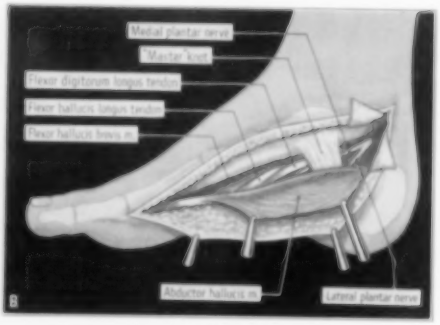


FIG. 1-B

Fig. 1-A: The skin incision follows the skeletal plane on the medial side of the foot, extending from behind the head of the first metatarsal to a point one-half of an inch below the medial portion of the malleolus.

Fig. 1-B: The abductor hallucis is reflected and an incision is made in the laciniate ligament in order that the medial and lateral plantar nerves may be exposed.

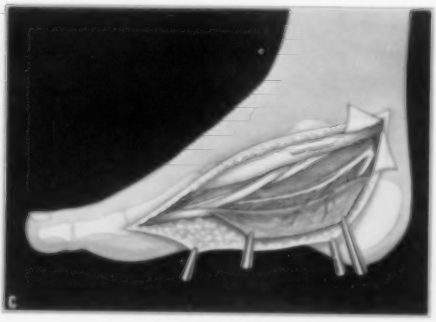


FIG. 1-C

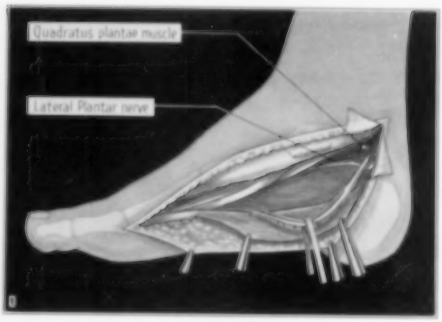


FIG. 1-D

Fig. 1-C: The medial plantar nerve is exposed and is mobilized by incision of the "master" knot branches which supply the plantar muscles. Note the large sensory branch just lateral to the main trunk.

Fig. 1-D: The lateral plantar nerve is exposed, and its branch to the quadratus plantae is shown. Note the medial plantar nerve, of which only the sensory components remain.

## ANATOMY

The authors first became interested in the anatomy of cavus deformity after examining a child in whom the short flexors of the toes and the abductor hallucis were the only muscles below the knee that were not completely paralyzed. All of the leg muscles in this child were graded *zero* since they did not partake in the deformity except in a negative manner. The deformity was cavo-adductus, and the involved foot was two shoe sizes smaller than its mate. Since this foot could not be further harmed, the authors decided to perform a selective motor neurectomy on the muscles in the sole. Several weeks after this operation the mother reported that the child's foot was one size larger than it had been. Since that time the authors have performed the operation on carefully selected patients.

### *Medial Plantar Nerve*

The abductor hallucis arises from the medial process of the tuberosity of the calcaneus, from the laciniate ligament, and from the plantar aponeurosis. Its tendon inserts into the proximal phalanx of the large toe in the region of the medial sesamoid bone.

The flexor hallucis brevis originates from the plantar surfaces of the cuboid and third cuneiform and from the prolongation of the tendon of the tibialis posterior. It divides into two tendinous branches, these branches both inserting into the base of the proximal

phalanx of the great toe. A sesamoid bone is present in each tendon at the point of insertion.

The flexor digitorum brevis arises from the medial process of the calcaneal tuberosity and from the plantar aponeurosis. Its four branches insert into the middle phalanges of the four lesser toes.

The lumbrical muscles of the foot arise from the tendons of the flexor digitorum longus and insert into the dorsal aponeuroses of the four lesser toes. By their action these muscles flex the proximal phalanges and extend the other phalanges. The first and second lumbrical muscles are said to be innervated by the medial plantar nerve, but the other lumbricales are supplied by the lateral plantar nerve.

*Lateral Plantar Nerve*

The quatratus plantae arises from the calcaneus and from the long plantar ligament. It inserts into the tendon of the flexor digitorum longus and thus is an accessory flexor of the toes.

The adductor hallucis has two heads, an oblique head which arises from the plantar surfaces of the bases of the three middle metatarsal bones and from the sheath of the peronaeus longus tendon and a transverse head which arises in the region of the tarsophalangeal joints of the third, fourth, and fifth toes. The tendons of these two heads combine and insert into the proximal phalanx of the great toe in the region of the lateral sesamoid. By the action of this muscle the great toe is adducted and flexed.

The lateral plantar nerve also innervates the seven interossei and the other small muscles of the foot. The interossei flex the proximal phalanges and extend the other phalanges.

## INDICATIONS

The indications for the performance of plantar-muscle denervation appear to be simple. The operation should be considered if the deformity is increasing and if it does not respond to conservative therapy.

If possible, it is advisable to perform the operation before the patient has gone through the last period of rapid growth. The authors have not operated upon any adults, and their oldest patients have been sixteen and seventeen years of age. In these two patients, growth had practically ceased and there was, therefore, little change in the shape of the foot; in performance, however, improvement was noted. The authors have not observed that any ill effects have occurred as a result of the operation.

## TECHNIQUE

The operation is performed by means of the approach described by Henry. The incision follows the skeletal plane of the inner border of the foot, extending from behind the head of the first metatarsal to a point approximately one-half inch below and anterior to the medial malleolus. If necessary, this incision may be extended posteriorly around the malleolus. The fascial reflection of the abductor hallucis is incised, and the muscle is reflected soleward. In this manner two openings in the muscles are made, one distally between the abductor hallucis and flexor hallucis brevis and one posteriorly between the abductor hallucis and flexor digitorum brevis. The medial plantar nerve may then be found just inferior and lateral to the tendons of the flexor hallucis longus and the flexor digitorum longus. This nerve is isolated and its branches to the abductor hallucis are elevated by means of a nerve hook. The branches are stimulated, and those which cause contraction of the muscle are severed, for any contraction of the muscle increases the arch of the foot. After this procedure the nerve is further followed, and its branches to the flexor hallucis brevis and flexor digitorum brevis are identified and elevated. Again the branches are stimulated and those which cause contraction of the muscles are severed.

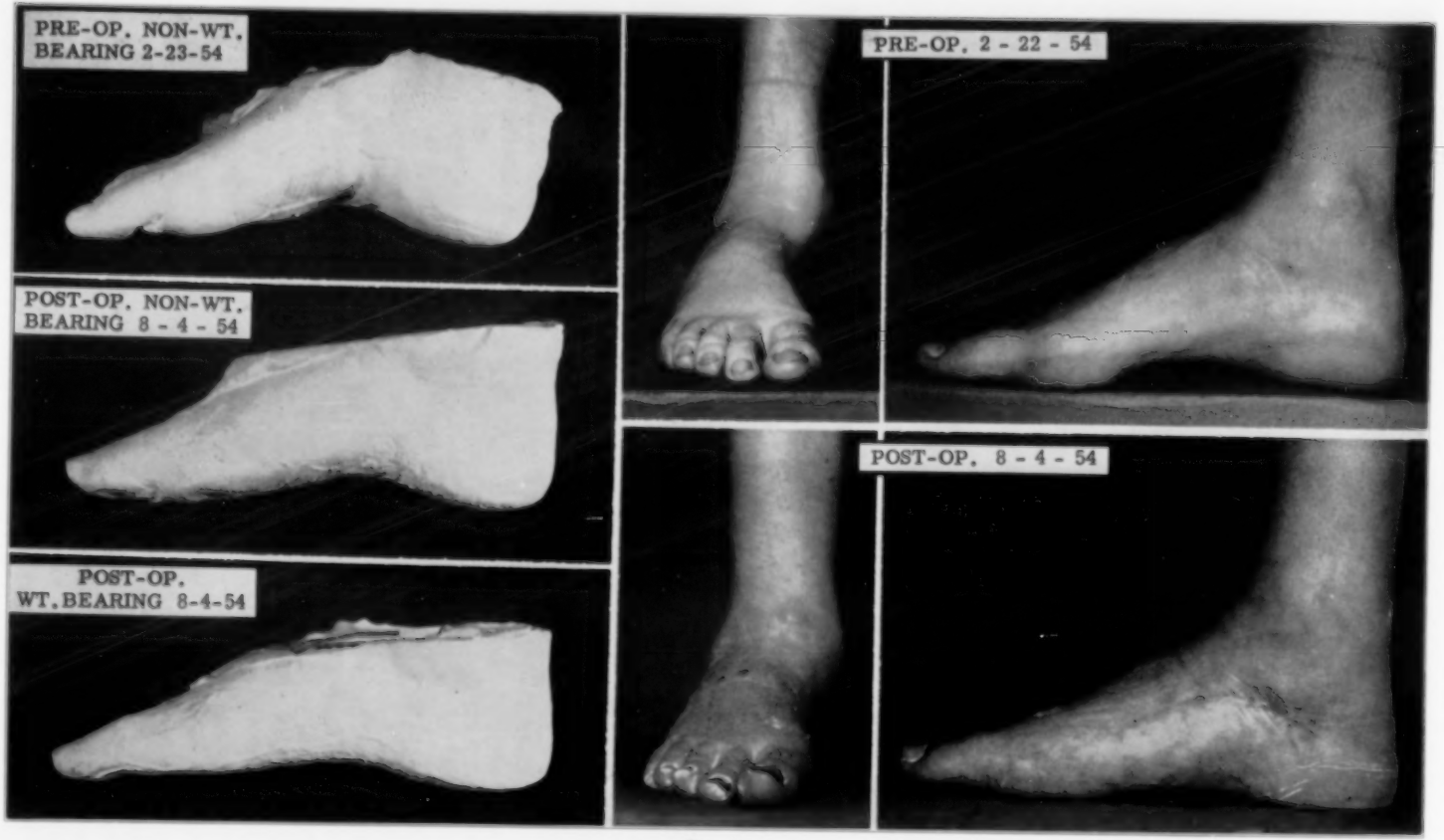


FIG. 2

M. W., 140465, a fifteen-year-old girl, had poliomyelitis in 1943. Triple arthrodesis of the right foot and transfer of the peronaeus longus tendon to the Achilles tendon was done in February 1950; denervation of the quadratus plantae was done in February 1954. Note the improvement in the adductus and cavus deformities.

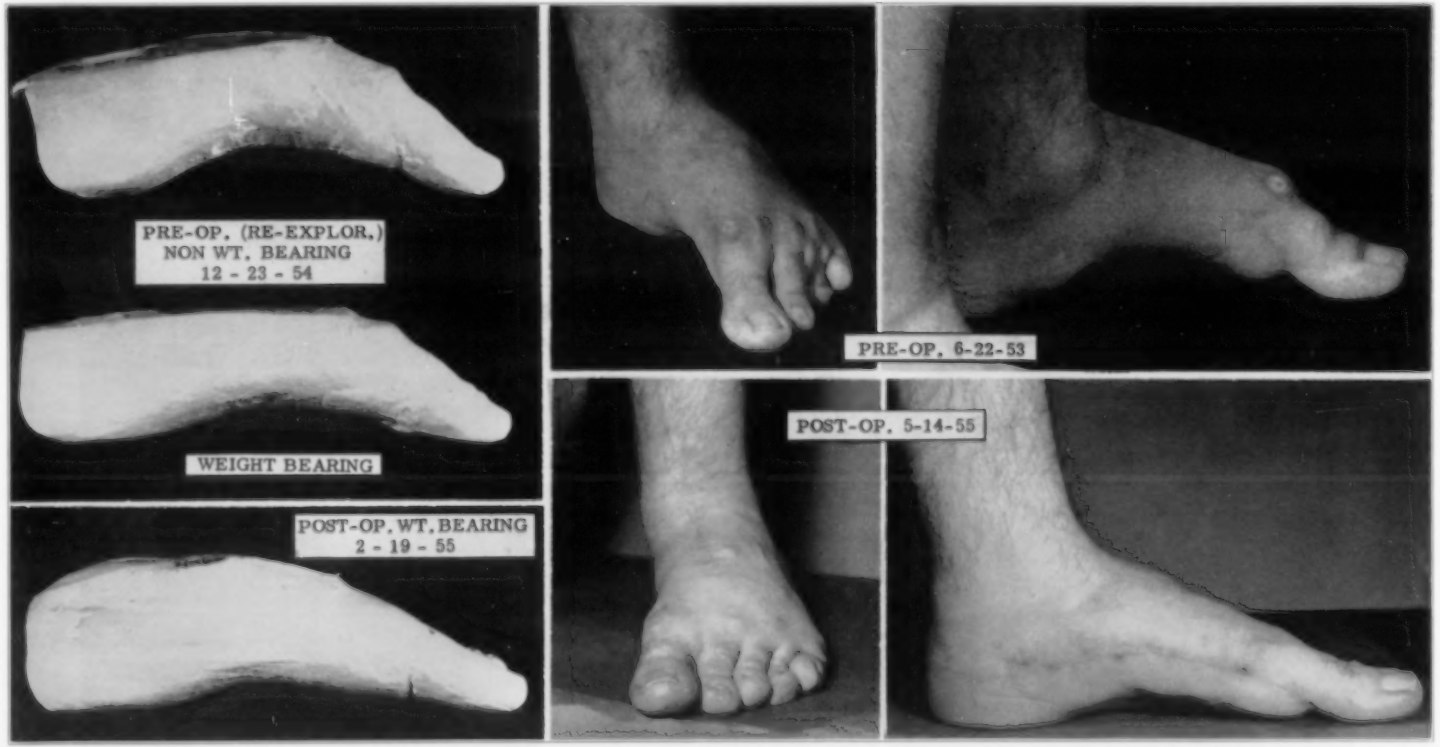


FIG. 3

J. G., 82070, a sixteen-year-old boy, had a cavo-adductus deformity with a dorsal bunion as a result of poliomyelitis. Triple arthrodesis was done in 1947, and selective denervation was done in June 1953. In December 1954, the foot was re-explored, and, in an effort to treat the dorsal bunion, the flexor hallucis brevis was denervated. Note the improvement in the bunion and in the cavus deformity.

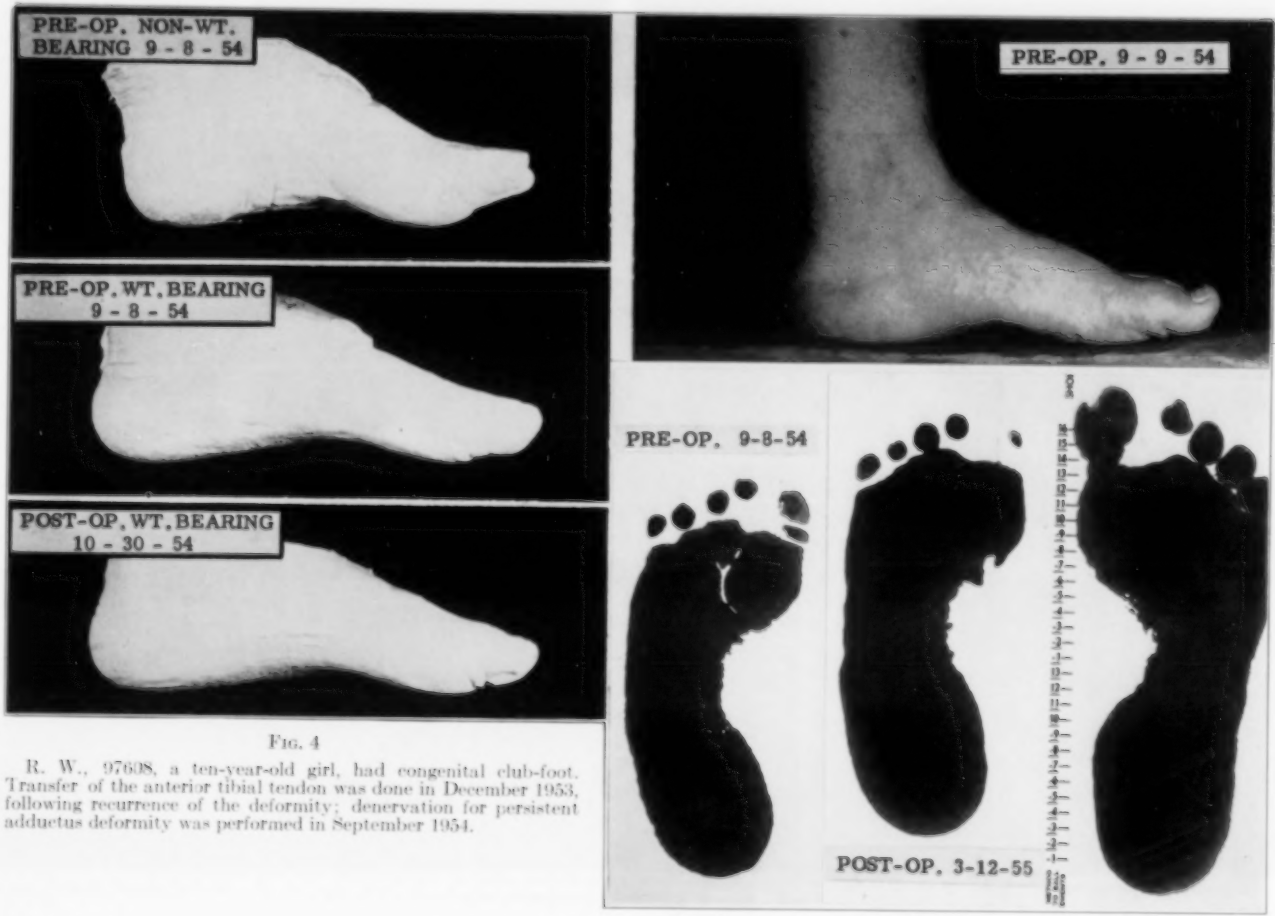


FIG. 4

R. W., 97698, a ten-year-old girl, had congenital club-foot. Transfer of the anterior tibial tendon was done in December 1953, following recurrence of the deformity; denervation for persistent adductus deformity was performed in September 1954.

The lateral plantar nerve is located by tracing the medial nerve posteriorly until it passes under the laciniate ligament. At this point the medial nerve is retracted either upward or downward, by means of a soft Penrose rubber tube, and the lateral nerve is exposed. The lateral nerve in this area dips downward, between the flexor digitorum brevis and the quadratus plantae, in preparation for coursing laterally and obliquely across the sole. The small branches of the lateral nerve which lead to the quadratus plantae are elevated and stimulated, and the branches which cause contraction of the muscle are severed.

Following this procedure, the main trunks of both nerves are again stimulated in order that it may be determined if the muscles can still be contracted sufficiently to increase any cavus deformity that remains. If the results are positive, a search is made for motor branches that have not yet been severed. It cannot be overemphasized that only those branches which cause contraction of the muscles should be severed; the other branches are purely sensory.

Closure of the wound is a simple procedure since the exposure has been made entirely within intermuscular planes. The "master" knot of fibrous tissue is reattached to the subcutaneous tissue, and the skin is closed loosely by means of continuous silk. Following the operation the foot is immobilized in a plaster boot; this immobilization is usually continued for only three weeks, but occasionally a longer period may be indicated. Healing occurs with a minimum of scar formation.

## METHOD OF STUDY

Before the operation and at various times after the operation, plaster molds of the foot are made with the patient in the weight-bearing and non-weight-bearing positions. For visualization of the results, this method of study appears to be the best. Other methods of study are also used, however, and these include the following: (1) photographs are made both before and after the operation; (2) footprints are made; (3) the size of the patient's shoe is recorded; (4) the calluses which may be observed on the patient's footprint are noted; and (5) if a brace is used, the size of the brace is recorded.

## RESULTS

In the authors' series of cases forty-seven feet were available for study, a sufficiently long period of time having elapsed since the operations for the preliminary results in these feet to be apparent. In this study the authors used both objective and subjective criteria, evaluating the improvement in performance according to (1) the patient's observation of decrease in fatigue; (2) diminution in or disappearance of calluses; and (3) improvement in the patient's gait and in the stability of the foot. The longest period of follow-up was thirty-four months. The patients ranged in age from four and one-half years to seventeen years. The distribution as to sex was about even.

In no patients were unfavorable results observed. There were no flat feet, and no neurotrophic changes had occurred. Furthermore, it was felt that if care was taken to preserve the sensory nerves, no sensory changes should take place. Since the patients' balance had improved, it was apparent that there had been no noticeable disturbance in the proprioceptive sense.

In the patient in whom the deformity was caused by arthrogryposis there was no improvement. In the remaining patients, however, some degree of benefit had been obtained. Furthermore, continued benefit could be expected in these patients, for since the time of the operations, all the involved feet had shown progressive improvement.

### *Post-Poliomyelitic Group*

In this group, there were twenty-eight patients, twenty-six with unilateral involvement and two with bilateral involvement. In almost all of these patients, depression of

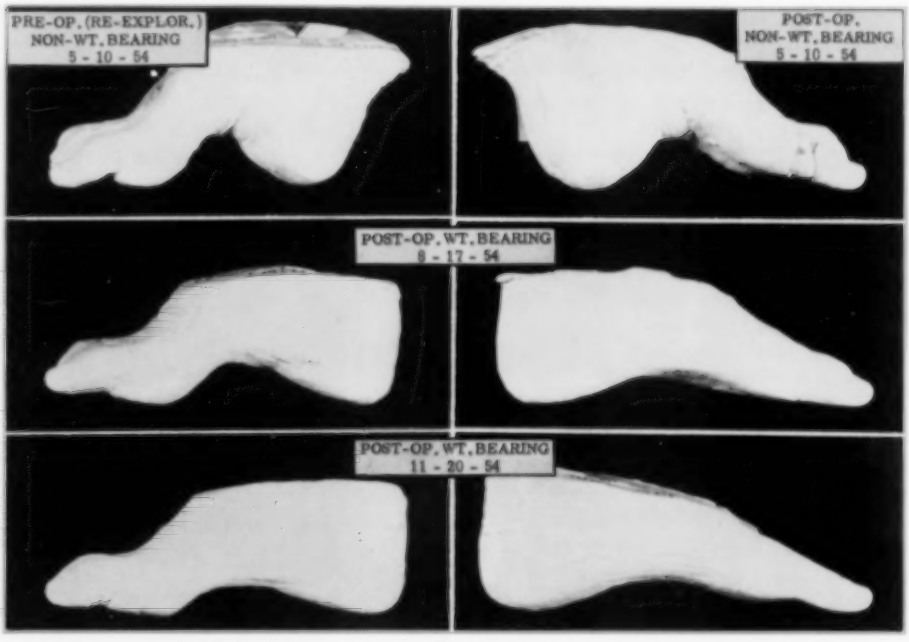


FIG. 5

S. L., 130276, an eleven-year-old girl, had bilateral congenital pes cavus. Bilateral plantar fasciotomy and transfer of the extensor digitorum longus tendon was done in 1949. Bilateral denervation was done in 1953.

the arch and correction of the adduction of the fore part of the foot occurred following the treatment. If the deformity was cavo-adductus, the cavus aspect responded better than the adductus aspect. Of the sixteen patients who had originally worn mismated shoes, ten were able to wear shoes of the same size following the treatment. This side effect is significant, for it makes a larger selection of styles available, a factor of psychological importance to youngsters.

In twelve patients, there had originally been a large callus under the base of the fifth metatarsal; in only one of these patients did the callosity persist after the operation. The resolution of a painful callosity is important, for it permits the resumption of a normal gait.

Twenty-two of the twenty-eight patients reported improved performance of the foot, this improvement being evidenced by better balance, smoother gait, greater endurance in weight-bearing, and greater ability to wear braces. In all of these patients the improvement could be attributed to correction of the deformity and to increased stability of the foot.

*Congenital Pes Cavus*

The results obtained in the patients with congenital pes cavus were not dramatic; nevertheless, from the functional standpoint of improved performance and from the economic standpoint of less expensive footwear, sufficient benefit was obtained to justify the use of the procedure. On the basis of this study it appears that the operation should be performed before full structural growth of the foot has been attained.

Improved performance of the foot was reported by all the patients in this group, including the two patients who were operated upon when sixteen and seventeen years of age. Several years of observation will be required, however, before final evaluation can be made of the results obtained in the patients who were operated upon when less than twelve years of age.

*Congenital Talipes Equinovarus*

A residual cavo-adductus deformity sometimes occurs following incomplete correction of congenital club-foot. In the authors' series two feet with this deformity were operated upon. Both these feet appeared to be much improved as a result of the operation, but more time will be required before a final evaluation of the benefit obtained can be made. On the whole, the use of the authors' procedure would seem to be justified in cases of residual cavo-adductus deformity.

*Arthrogryposis*

One patient with a residual club-foot deformity had arthrogryposis. In this patient no improvement was obtained by the treatment. Although it appeared that no harm had been done, the authors believe that their operation should not be done upon the feet of patients with arthrogryposis because of the nature of the abnormalities which are present in the muscles, ligaments, and joints.

*Pes Cavus of Undetermined Origin*

In this group there were three patients, two with unilateral involvement and one with bilateral involvement. The authors were unable to determine if the deformities in these patients were the result of infantile paralysis or if they were congenital in origin. In two of the three patients improvement in performance and appearance was obtained.

*Myelodysplasia*

No improvement was obtained in the one patient with myelodysplasia. The authors nevertheless believe that in most cases the cavus deformity which occurs in patients with myelodysplasia will respond to the operation; they feel that further study of this possibility should be made.

## SUMMARY

1. The authors believe that pes cavus is caused by imbalance of the intrinsic muscles of the foot and feel that the abductor hallucis, flexor hallucis brevis, flexor digitorum brevis, and quadratus plantae should be particularly studied. The long muscles are seldom involved in the development of this deformity.

2. Cavus deformity of the foot is usually progressive.

3. The preliminary results in the authors' series suggest that selective plantar-muscle denervation may prevent the progressive increase of pes cavus. This prevention will result in improvement in foot balance, performance, stability, and position, and these improvements in turn will stimulate better growth.

4. If the most favorable results are to be obtained, the operation should be performed as soon as possible, for, otherwise, as growth occurs, the bones will be molded into a shape that conforms with the deformed position of the foot.

5. The results to date suggest that the operation is indicated when the deformity is congenital or when it results from either infantile paralysis or congenital club-foot.

6. No ill-effects from the operation have been noted.

NOTE: The authors wish to thank Mr. James F. Glore, Head of the Department of Illustrations, Indiana University Medical Center, for his aid in preparing the schematic drawings and the graphs. They also wish to acknowledge the assistance of Paris C. Johnson, Edward K. Sims, and Louis McGinnis, members of the Department of Illustrations.

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## DISCUSSION

### Tumors of the Hand

*(Continued from page 524)*

may be dissected *en bloc* with the nodes. For tumors of the hand, however, I do not think this approach can be used, for it would be too difficult to dissect the lymphatics all the way from the thumb or index finger up to the axilla.

I was interested in Dr. Howard's discussion of the use of hydrocortone in the treatment of ganglia. In a recent issue of the *Journal of the American Medical Association* [a], it was stated that ganglia could be effectively removed by the injection of either hydrocortone or hyalonuidase. We tried this method of treatment in several of our cases. We did not obtain satisfactory results with it, however, and so returned to the performance of surgery.

Mention has been made of the interesting small tumors which arise from the distal interphalangeal joints and which are similar to ganglia. We have encountered seven of these tumors, all of which we excised. The tumors are usually found in kindly old ladies, and they almost always respond to radical excision. Skin-grafting is occasionally necessary. In our series there was only one instance of recurrence, this instance occurring, however, as one might expect, in the most talkative of the ladies.

The final results in the two physicians from whom glomus tumors were removed might be of interest. In the thirty-year-old physician the relief of pain was so great that he improved his golf game, taking five strokes off his score, much to the chagrin of his colleagues. In the seventy-year-old physician, the results were so good that he left his wife and ran off with his office nurse.

a. Queries and Minor Notes. Am. J. Med. Assn., **155**: 1022, 1954.

# The Importance of Plantar Muscles in Paralytic Varus Feet

## The Results of Treatment by Neurectomy and Myotenotomy

BY RALPH W. COONRAD, M.D., DURHAM, NORTH CAROLINA, C. E. IRWIN, M.D., THOMAS GUCKER, III, M.D., AND J. B. WRAY, M.D., WARM SPRINGS, GEORGIA

In lower extremities severely involved by poliomyelitis, the short toe flexors, lumbricales, and interossei are more commonly spared than are any other muscles. These muscles are frequently found intact in an otherwise totally flail extremity, and they have been mentioned by Goldner and Irwin, Crego and McCarroll, and Lovett as important factors contributing to the presence of both cavus and varus deformities in the paralytic foot. The authors' attention was particularly drawn to this problem in the fall of 1950, when the results in a number of nearly flail feet with recurrent talipes varus were evaluated postoperatively in order that the cause of recurrence might be determined. As a result of this study, it appeared that the plantar muscles were the sole deforming factor to which recurrence could be attributed. An attempt was then made to obtain follow-up evaluation of all the nearly flail varus feet which had been stabilized by triple arthrodesis at the Warm Springs Foundation between 1940 and 1949, inclusively. The results found are as follows:

Forty-seven nearly flail varus feet had been treated by triple arthrodesis and had been adequately followed. In twenty-two of these feet (46 per cent) talipes varus had recurred. Of these twenty-two feet with recurrent deformity, eighteen were found to have good plus (90 per cent) or better residual toe-intrinsic-muscle power, no other cause of the recurrence being apparent. In two feet there had been failure of fusion at the mid-tarsal joints; and in two other feet lateral tibial torsion of a significant degree, in addition to the presence of normal short toe flexors, lumbricales, and interossei, accounted for the recurrence. In the twenty-five feet in which no recurrence had occurred, the short toe flexors, lumbricales, and interossei had less than functional (60 per cent) strength. There was no evidence of tibial torsion or of pseudarthrosis in these feet.

Such findings indicated a definite need for elimination of the deforming action of the short toe flexors or of the lumbricales and interossei or of both in otherwise flail feet at the time of stabilization.

Goldner and Irwin have listed the following factors as contributing to the occurrence of talipes varus in a nearly flail foot:

1. The pull of the short toe flexors, interossei, and lumbricales (when these muscles are present), which contributes to adduction of the fore part of the foot;

2. Contracture of the plantar fascia, which fixes the cavus deformity;

3. External torsion of the tibia, which increases the tendency toward talipes varus of the entire foot with its relaxed ankle and tarsal joints. Torsion of the tibia in a braced extremity produces varus deformity of the fore part of the foot and later of the heel; this is particularly true when a pelvic band is worn, since this band prevents outward rotation of the brace on the thigh and places the foot in a varus position. Abnormal distribution of body weight through the tarsal bones, after talipes varus has developed, tends to increase the varus deformity.

Such factors as the effect of gravity and the weight of bed clothing also contribute to the development of talipes varus in the completely or nearly flail extremity.

The recurrence of a varus or cavo-varus deformity in a paralytic foot following surgery may be due to any one of the following factors:

FIG. 1

FIG. 2

Fig. 1: A typical nearly flail varus foot in which only the plantar musculature can function.

Fig. 2: This photograph illustrates the action of the short-toe-flexor and intrinsic muscles in a nearly flail foot.

1. Failure of fusion, particularly at the calcaneocuboid or talonavicular joint;
2. Failure to eliminate completely varus deformity of the heel or the fore part of the foot at the time of surgery, which leaves the short plantar muscles at a mechanical advantage and enables them to act as a strong deforming factor;
3. Failure to correct lateral tibial torsion or rotation;
4. Failure to eliminate all muscular deforming factors in those feet which are not completely flail.

In the literature little emphasis has been placed on the persistent deforming action of the plantar muscles in the foot with paralytic deformities; there has also been little emphasis upon the treatment of this factor in a nearly flail lower extremity in which the plantar muscles alone remain functional. In 1917, Steindler described his well known stripping of the calcaneus, a procedure which is performed to obtain correction in certain cases of cavus deformity. Steindler realized that plantar fasciotomy in itself was unsatisfactory and that recurrences of cavus deformity were not uncommon. His procedure consisted in severing the attachments of all the small muscles of the foot and the plantar fascia which originate from the calcaneus. A report of fifty patients satisfactorily treated in this manner was made in 1920, and a report of an additional number of patients satisfactorily treated was made in 1927. As a method of treating cavus deformity, Sherman, in 1905, suggested anchoring the common toe extensors into their respective metatarsal heads. In 1919, Hibbs proposed that the primary Steindler stripping procedure be followed by transference of the common extensors into the third cuneiform. Neither of the last two procedures is applicable to the nearly flail type of varus foot under discussion. To our knowledge, no specific procedure involving the short toe flexors, the abductor hallucis, or the lumbricales and interossei has been mentioned in the literature as a treat-

ment for deformities of the paralytic foot, with particular reference to the flail varus foot. The authors, in their treatment of this problem, are not concerned with the more commonly encountered equinovarus foot in which there is contracture of the Achilles tendon, cavus deformity, contracture of the plantar fascia, depression of the first metatarsal head, and clawing of the toes.

The evolution of the authors' treatment of the plantar musculature in the nearly flail varus foot is of interest because of the approach used. Early in their evaluation of this problem it was felt that a neurectomy of the nerves to the short toe flexors and abductor hallucis would be sufficient. Cadaver dissections showed that the nerve branches to the individual muscle bellies could be severed through a plantar-fasciotomy incision and that by the extension of this incision a little further proximally, the larger branch from the medial plantar nerve could be identified and severed. Neurectomies, both high and close to the muscle bellies, were initially performed upon seven feet. These feet all showed improvement with some loss of toe-flexor function, but from the standpoint of what was technically desired, the results in these feet were unsatisfactory. In four of the feet, recurrent varus deformity of the fore part of the foot later developed.

Because of the postoperative presence of some residual flexor function in the toes, it was felt that possibly not all branches to these muscles were being severed; therefore, a less time-consuming and surer method was adopted. In this method a large section of both the muscle mass and the tendon origins of the short toe flexors was removed. In a few of the first operations, myotenotomy of the abductor hallucis was also carried out; an evaluation of the results showed, however, that little difference in the residual strength of flexion in the great toe was achieved by the latter procedure. (The abductor hallucis, by virtue of its insertion into the capsule and proximal phalanx of the great toe, is functionally stronger as a flexor than as an abductor.) In all, fourteen feet were treated by myotenotomy of the short toe flexors; in seven of these feet associated myotenotomy of the abductor hallucis was also performed. In one of the latter feet there was loss of flexor function in all the toes, a result which was considered satisfactory. In the remaining thirteen feet, however, there was only diminution in toe-flexor power, a result which was considered unsatisfactory. In four of these thirteen feet recurrent varus deformity of the fore part of the foot developed following stabilization.

At the time of surgery, the lumbricales and interossei were found to be of good color and excursion in several of the patients. Inasmuch as removal of the short toe flexors and abductor hallucis by neurectomy or simple excision would not alone produce a satisfactory result, it was felt that these lumbricales and interossei, which could not be adequately and separately tested beforehand, were at fault and that they should be functionally ablated either by neurectomy or excision. Thereafter nineteen patients were treated by a combination of myotenotomy of the short toe flexors and neurectomy of the deep branch of the lateral plantar nerve through the plantar fasciotomy incision. The results obtained by this combined procedure were considerably better than those obtained by neurectomy of the larger branch of the medial plantar nerve or by myotenotomy of the short toe flexors alone; satisfactory results were obtained in all nineteen patients. No flexor power of the toes was present in any of the feet, and in the seven patients followed for more than a year there has been no recurrence of the deformity of the fore part of the foot. The abductor hallucis and the abductor of the small toe were left intact, no significant function of the great or small toes being present as a result.

For the purpose of completing the study, lateral plantar neurectomy, without short-toe-flexor myotenotomy, was performed upon four patients. In these patients the flexor power of the toes remained a problem after the operation, and the results were unsatisfactory.

Tibial torsion was not a problem in these patients. If present, it was corrected surgically, and it remained corrected at the time of follow-up study.

SUMMARY

1. Of forty-seven nearly flail varus feet treated by triple arthrodesis between 1940 and 1949, twenty-two (46 per cent) had recurrent talipes varus; in ten of these feet the deformity was of sufficient degree to warrant surgical repositioning of the foot. Eighty-one per cent of the recurrences could be attributed to intact functional plantar musculature, which was the most important deforming factor.

2. Treatment of this problem consists in ablation of the deforming factor. According to the authors' preliminary evaluation, the best results have been obtained by severance of the deep branch (muscular) of the lateral plantar nerve and by myotenotomy of the short toe flexors at the time of plantar fasciotomy and stabilization, the same plantar incision being used for all the procedures.

3. Similar treatment appears to be indicated for the child who is too young for stabilization but who has functional plantar musculature in an otherwise flail varus foot.

4. Neither neurectomy of the medial plantar nerve (or of its branches) alone nor myotenotomy of the short toe flexors and abductor hallucis alone is generally satisfactory in producing ablation of toe-flexor power in the paralytic varus foot. Neurectomy of the deep branch of the lateral plantar nerve alone has similarly been found inadequate.

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# Experiences with Lengthening of the Femur over an Intramedullary Rod *

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A major problem in the procedures devised for the lengthening of the long bones has been to find a satisfactory means for controlling the alignment of the fragments. A long nail placed in the medullary cavity has been used to control the alignment of the fragments in fractures of the femur. When it was observed that the distraction of the fragments on the nail, which occurred in some instances when traction was being applied to the distal fragment, did not disturb the alignment of the fragments, the intramedullary nail was incorporated in the procedure for the lengthening of the femur. This is a report of the authors' experiences with the use of the intramedullary nail in lengthening of the femur in twenty-three operations performed upon twenty patients since January 1951.

The operations for the lengthening of the long bones, always encumbered with difficulties and complications, have justly never become a popular means of meeting the problems presented by the patient whose lower extremities are unequal in length. In the solution of these problems a far greater usage has been rightly accorded to the less difficult and less complicated procedures designed by Phemister and Blount and Clarke for the blocking of the growth of the epiphysis by epiphyseodiaphyseal fusion and epiphyseal stapling and to the operations for the shortening of the longer limb described by various other surgeons.

In some patients, however, the inequality may be too great or the condition encountered too late to permit a solution by these less complex procedures. This may be especially true in patients in whom there is a congenital disturbance of growth, in those in whom the growth of one limb has been greatly disturbed at an early age either by trauma or disease, and in those patients who are already of an unusually short stature. To these patients the lengthening of the femur offers the only alternative to the life-time use of an unwieldly brace appliance or an artificial limb. For these obvious reasons and because they have long had an interest in the operation for lengthening the limb, the authors undertook a clinical study that forms the basis of this report.

## SURGICAL TECHNIQUE

In doing this procedure use was made of the many essential principles which have been developed by other orthopaedic surgeons who have performed this operation in the past. The innovations introduced in this report of the operation for the lengthening of the femur are concerned with the position of the patient on the operating table, the incision for the exposure of the femur, the use of the intramedullary rod, and the employment of a simple transverse osteotomy of the femur.

### *Position of the Patient*

Formerly, some difficulty was experienced in the introduction of the Steinmann pins into the proximal fragment of the osteotomized femur when the patient was placed in the supine position on the operating table. These pins, so essential for counter-traction, must be placed through the proximal end of the femur in a vertical or vertical-oblique direction

* Read at the Annual Meeting of The American Orthopaedic Association, White Sulphur Springs, West Virginia, June 22, 1955.

FIG. 1

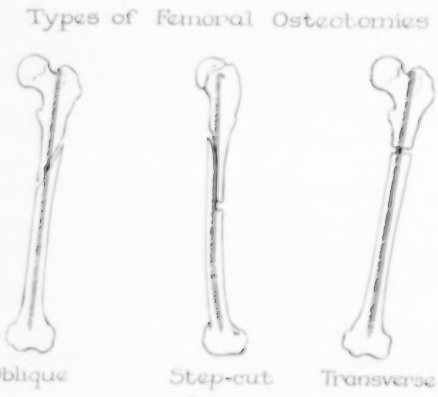



FIG. 2

Fig. 1: Patient in the lateral position on the Bell fracture table with the Castle pelvic-anchor sacral rest.

so that they emerge posteriorly in the buttock or upper thigh. In order to do this, it was necessary to suspend the limb or to have the thigh bridge a gap in the table so that only the elevated trunk and the lower portion of the limb are supported, but this left the osteotomized fragments of the femur in an unstable position. This difficulty has been eliminated by placing the patient in the lateral position, which can be ideally maintained by the use of the Bell fracture table and the Castle pelvic-anchor sacral rest (Fig. 1). This apparatus locks the pelvis firmly at three points thus securing the patient in the lateral position throughout the operation. This position permits both free access to the thigh and the gluteal region and effective draping of the hip and of the entire limb, which may be moved about without fear of contaminating the operative field. In addition, the pelvis is completely stabilized by the post against the ischium, which also affords a perfect means of countertraction. The lateral position is the best one for the exposure of the femur for the osteotomy and also for the insertion of the intramedullary rod.

*Incision*

The incision which has been found most practical both for the exposure of the femur and for the insertion of the intramedullary rod is the modification of the Kocher posterolateral incision described by Gibson. The skin incision parallels the shaft of the femur and curves gently posteriorly from the superior aspect of the greater trochanter toward the iliac crest. The incision may be extended, either proximally or as far distally on the thigh as is desired, for the complete exposure of that portion of the femur through which the osteotomy is to be performed. When insertion of an intramedullary rod is part of the procedure for lengthening of the femur, the posterolateral approach described by Gibson is superior to the anterolateral incision of Henry. The authors had formerly used Henry's approach for the femoral lengthening but now prefer not to use it, since a second incision is required for the insertion of the intramedullary rod.

*Exposure*

Division of the fascia lata and gluteal fascia is made in the same line as the skin incision. The entire length of the vastus lateralis can be exposed through this approach and reflected anteriorly from the lateral intermuscular septum to expose that portion of the shaft of the femur through which the osteotomy is to be performed. The origins of the vastus medialis and vastus intermedius are elevated from the femur to expose the anterior aspect of the shaft. Posteriorly the lateral and medial intermuscular septa are stripped from the linea aspera as far proximally and distally as required to release the soft tissue

from the bone. The fascial layers are cut completely and reflected from around the circumference of the femur at the osteotomy level.

The exposure of the greater trochanter is accomplished by reflection of the glutaeus medius and glutaeus minimus anteriorly and the glutaeus maximus posteriorly. These muscles need not be detached from their insertions since enough exposure to insert an intramedullary rod is easily obtained by retraction of their margins.

*The advantages of the Gibson exposure* are that it makes it possible to divide the origin of the vastus lateralis completely. This gives free access to the femur for the purpose of performing either the oblique or the step-cut osteotomy. When the transverse osteotomy is to be performed, the Gibson approach facilitates the cutting of the sleeve of the periosteum above or below the osteotomy site. This exposure also makes possible the division of the fascia lata and the attachments of the intermuscular septa at the linea aspera which must be performed routinely in order to release the soft tissues of the thigh.

*Osteotomies*

*The step-cut osteotomy* is planned so that the tongues of bone will slide on each other in the lengthening process. They must be made long enough to maintain bone contact throughout the lengthening process. The authors make the osteotomy in such a way that the anterior tongue is continuous with the distal part of the femur and the posterior tongue continuous with the proximal part of the femur. This is done in order to make use of the tension of the iliopsoas which tends to pull the proximal fragment against the distal fragment. This is, perhaps, unimportant when an intramedullary rod is inserted to control alignment of the fragments.

*The oblique osteotomy* is usually carried out in the sagittal plane. In most cases, the osteotomy is begun just below the base of the greater trochanter and the femoral shaft is cut at an oblique angle distally for about four inches. This osteotomy is also planned to maintain bone contact throughout the lengthening procedure.

*The transverse osteotomy* is the least difficult to perform. After exposure of the upper two-thirds of the femoral shaft, a sleeve of periosteum is made by cutting the periosteum transversely around the femur and stripping it upward or downward to the level of the osteotomy usually at the junction of the proximal and middle thirds. The femoral shaft is cut transversely with a motor saw or a Gigli saw, as preferred. The periosteal sleeve is then replaced. The intramedullary rod may be inserted from above over a guide or, after the osteotomy is made, it can be inserted retrograde into the proximal fragment and then driven in the opposite direction into the medullary canal of the distal fragment.

*The Intramedullary Rod*

In the lengthening of the femur, it is essential to control the alignment and the position of the osteotomized fragments of the femur at all times. The intramedullary rod was found to be very effective for this purpose. Any of the rods now being used for internal fixation of fractures may be utilized in femoral lengthening. Care must be taken to select an intramedullary rod with a diameter sufficiently small to allow distraction of the fragments, but yet heavy enough to prevent bowing. The rod may loosen and migrate proximally during the lengthening. This can be prevented by securing it at the greater trochanter by means of a wire passed through a drill hole in the rod.

*Discussion of the Various Osteotomies and the Intramedullary Fixation*

In the past, the conventional procedures for lengthening the femur were the step-cut osteotomy and the long oblique osteotomy (Fig. 2). These osteotomies were utilized because a constant contact between the fragments of the bone was maintained during the process of its lengthening by traction. The contact of the bone fragments was formerly considered an essential for the successful union of the fragments of the bone to take place.

There are disadvantages in both procedures, however; the step-cut osteotomy may leave a fragile tongue which is easily fractured and both the step-cut osteotomy and the oblique osteotomy may be unsuitable for the lengthening of very short bones.

In the very short bone, the long oblique and the step-cut osteotomies may not leave sufficient place for the insertion of the pins which are necessary to the traction and countertraction, and, if the length of the osteotomy is greatly reduced, the overlapping portions are soon separated by the lengthening of the bone. In using the intramedullary rod as a means of fixation of these osteotomies, it was found that the medullary canal proximal and distal to the site of the osteotomy was too short to hold the rod firmly through the whole lengthening process, thereby impairing the stability with the result that the alignment of the osteotomized fragments was not maintained (Fig. 3). For these reasons and because of a recollection of the experience reported by Abbott and Saunders in 1939 of the successful lengthening of the callus of a transverse fracture of the femur, the authors were encouraged to perform transverse osteotomy of the femur over an intramedullary rod.

FIG. 3

Roentgenograms show the position of femoral fragments five days after a step-cut osteotomy (left) and two months after osteotomy (right). In this very short femur this type of osteotomy resulted in instability.

The transverse osteotomy has been performed by the authors in various ways in femoral-lengthening operations, both with and without the use of the traction-countertraction apparatus. The simplest procedure is found to be that of first introducing the intramedullary rod into the femur from the greater trochanter to the distal epiphysis and thereafter making a posterolateral incision and exposing the femur. In other instances, the exposed femur is transected and the intramedullary rod is driven first proximally through the temporarily displaced proximal fragment and then re-directed into the medullary cavity of the distal fragment. A third method is that of exposing the femur in its upper two-thirds through the described Gibson approach, thus permitting the performance of the osteotomy, the intramedullary pinning, and the release of the soft tissues under the direct vision of the surgeon. However, by introducing the intramedullary rod first before the osteotomy is performed, the operation for the lengthening of the femur is greatly reduced in magnitude.

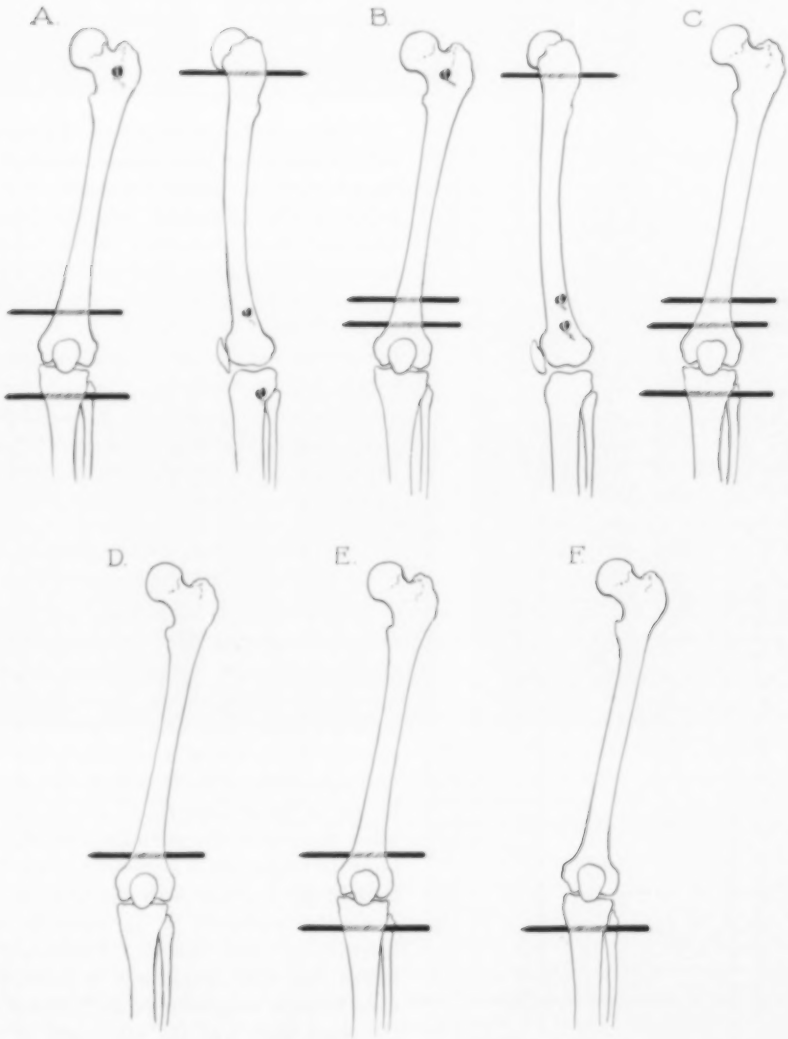
*Insertion of Traction and Countertraction Pins*

*Countertraction.* No insurmountable difficulty is encountered in the introduction of the Steinmann pins into either the proximal or the distal femoral fragment when an intramedullary rod is used. It is possible to avoid contact with the intramedullary rod and to transfix the bone. One or two pins are placed in the upper end of the femur for the purpose of providing countertraction. A single pin is usually adequate. The threaded stainless-steel pin, three-sixteenths or one-quarter of an inch in diameter, is directed from the anterior aspect of the femur posteriorly in the sagittal plane, usually between the lesser trochanter and the base of the femoral neck. It does not seem to matter whether the pin passes on the

medial or on the lateral side of the intramedullary rod. The pin is driven through the bone and appears posteriorly in the upper thigh or lower buttock.

*Traction.* More than one traction pin is usually necessary in the distal fragment because of the strong force exerted during the lengthening procedure (Fig. 4). The best method seems to be to drill one pin through the distal end of the femur and another through the proximal end of the tibia. The femoral traction pin is placed transversely at the junction of the shaft and the supracondylar ridges. The tibial pin is drilled parallel to this through the tibia at the level of the tibial tubercle. Traction is exerted upon both pins as a unit by means of the distraction apparatus.

If heavy continuous traction is applied to the distal femoral fragment only, compression of the articular surfaces of the knee joint results, due to the resistance of the hamstring




Skeletal-Pin Arrangements

FIG. 4

Fig. 5

Fig. 5: Femoral-lengthening distraction apparatus used on some of the patients in this series.

muscles which are inserted into the tibia. Conversely if continuous heavy traction is exerted on a tibial pin alone, overstretching of the capsule and ligamentous supports of the knee joint may be produced. The resultant unstable knee joint frequently is a troublesome complication. When the traction force is exerted on two pins, one in the femur and one in the tibia, the force is distributed across the knee joint thus protecting it against compression or stretching injury.

*Ancillary Procedures*

On a number of occasions, the release of soft tissues other than those described have been carried out. These procedures are lengthening of the hamstring tendons from the tibia and fibula, tenotomy of the tendon of the adductor magnus, and the release of the insertion of the adductor magnus. The release of these soft tissues requires incisions which are not the same as those used to expose the femur. Although previously found useful in some instances, the release or lengthening of the tendon of the quadriceps femoris has not been done in any of the operations performed upon the group of patients forming this series.

## LENGTHENING OF THE FEMUR FOLLOWING THE OPERATION

Two methods have been employed to apply the traction and the countertraction that are necessary for the lengthening of the femur after the operation. These are: traction upon the limb which is suspended in a Thomas splint and the use of a traction-countertraction apparatus (Fig. 5), which was designed by one of the authors (F. C. B.) in 1931. Because the rod in the medullary cavity maintains the fragments in alignment, it was hoped that simple traction with the Thomas splint would be sufficient in all cases in which lengthening was desired. Experience has shown that this simple way is sufficient for most femoral lengthenings, particularly when the short limb was the aftermath of poliomyelitis, trauma, or an arrest of the growth of the epiphysis from some disease or compression. This method, however, was not

FIG. 6-A

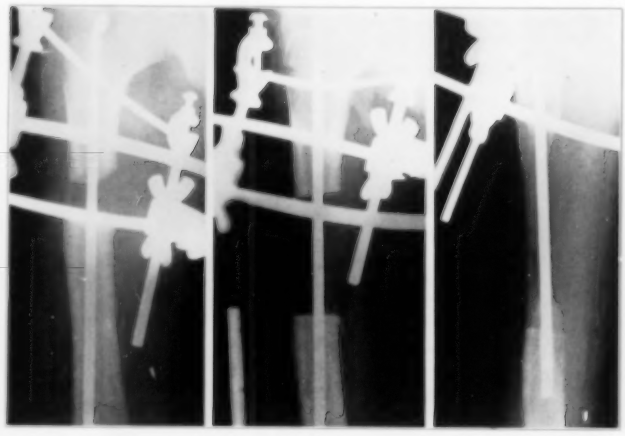


FIG. 6-B

Fig. 6-A: Patient I. M. Preoperative roentgenogram showing three and three-eighths inches of congenital shortening of the right femur.

Fig. 6-B: Series of roentgenograms showing progression of femoral lengthening two weeks, seven weeks, and twenty-seven weeks after a transverse osteotomy; the intramedullary rod and the distraction apparatus control the alignment of the fragments.

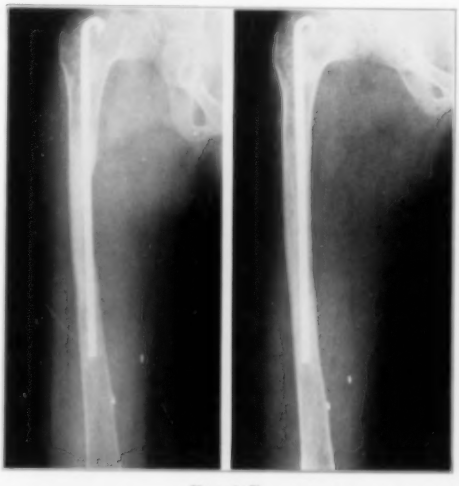


FIG. 6-C

FIG. 6-D

Fig. 6-C: Roentgenograms made fifteen months and twenty-seven months after osteotomy show gradual development of the medullary canal after lengthening and union.

Fig. 6-D: The result after two years showing the restitution of the cortices and the medullary canal after a gain in length of three and seven-eighths inches.

effective for the lengthening of limbs which are short because of a congenital disturbance of their growth. The reason for the difference in the effectiveness of the two methods appears to be due to differences in the strength and in the elasticity of the soft tissues and of the muscles. In the cases of shortening resulting from congenital disturbance of growth, a satisfactory degree of lengthening was obtained in a number of patients only by using the traction-countertraction apparatus.

Traction is started immediately after the operation and is continued at a low rate until the desired length is obtained or until no further length is obtainable. Sometimes the lengthening is discontinued because of the occurrence of some complication which

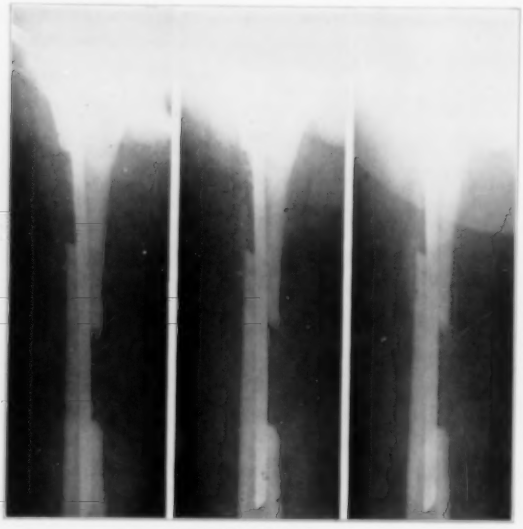


FIG. 7-A

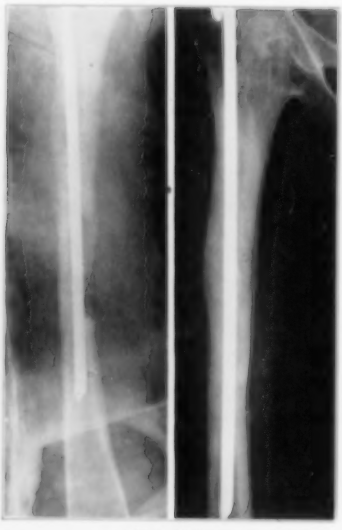


FIG. 7-B

Fig. 7-A: Patient S. Y. Roentgenograms made during the lengthening procedure nine days, sixteen days, and twenty-one days after an oblique osteotomy. The intramedullary rod and a Thomas splint control the alignment of fragments. The shortening had resulted from tuberculous arthritis of the hip and arthrodesis.

Fig. 7-B: Roentgenograms made three months after osteotomy and the end-result roentgenogram made one year after operation showing a two-inch gain in length.

FIG. 8-A

Patient W. D. Roentgenograms made fifteen days, twenty-two days, and twenty-nine days after transverse osteotomy showing early callus formation. An intramedullary rod and Thomas splint control the alignment of the fragments.

makes its cessation obligatory. In any event, traction is usually maintained until union of the bone appears to be sufficiently strong to permit the substitution of a plaster spica incorporating one of the distal pins for fixation. The pin used for the fixation is removed as soon as possible and ambulation with weight-bearing is permitted. The cast is maintained for as long a time as is necessary.

Throughout the process of the lengthening, careful attention must be given to such

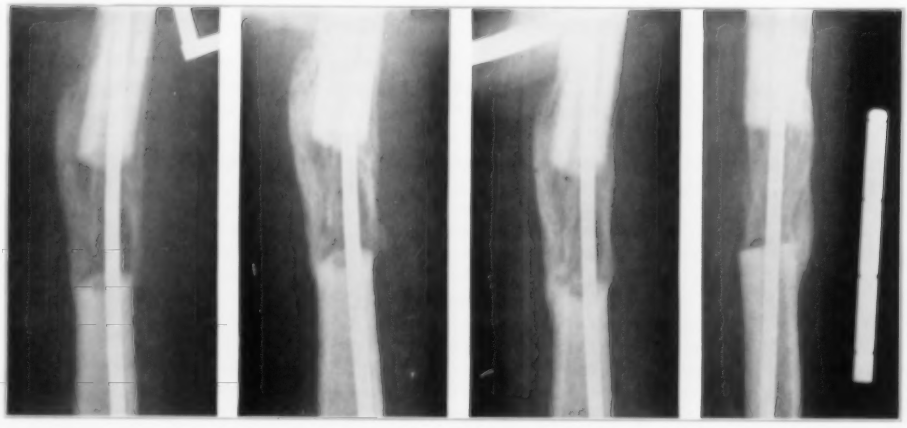


FIG. 8-B

Early bridging of the defect created by the osteotomy and lengthening is visible in three roentgenograms. The two on the left were made postoperatively at thirty-seven and forty-two days, respectively, and the two on the right were both made after sixty days.

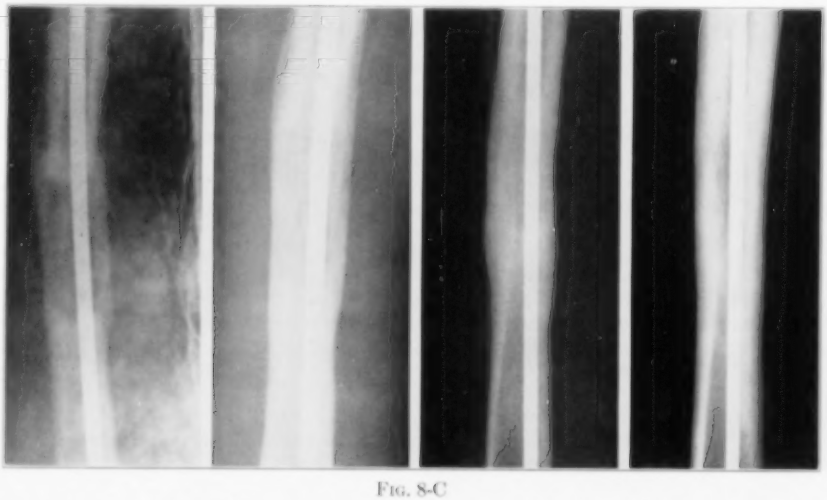


FIG. 8-C

Roentgenograms made four months, six months, one year, and two and one-half years after osteotomy show remodeling of the lengthened segment of the femur.

important details as the onset of pain, too rapid lengthening, the occurrence of vascular or neurological disturbances or any of the many other complications. Prevention of these complications requires the eternal vigilance of the surgeon who performed the operation.

## ANALYSIS OF THE RESULTS

In the past four years, January 1951 to January 1955, the operation for the lengthening of the femur over an intramedullary rod was performed twenty-three times on the femora of twenty patients. Three femoral osteotomies were performed in one patient and two in another patient for the purpose of providing an increase in the length of the bone. These operations were all performed on children, the youngest being five and one-half years of age and the oldest fifteen years of age. The etiology of the shortening of the limbs of these patients was congenital shortening in seven patients, poliomyelitis in five

TABLE I

| Patient | Age (*Years*) | Etiology of Shortening | Type of Osteotomy | Length of Discrepancy (*Inches*) | Length Gained (*Inches*) | Time to Lengthen (*Weeks*) | Time for Union (*Weeks*) |
|---|---|---|---|---|---|---|---|
| I.M. | 6½ | Congenital shortening | Transverse | 3⅜ | 3⅞ | 27 | 55 |
| K.B. | 7 | Congenital shortening | Step-cut (first procedure) | 3½ | ⅜ | 3 | 3 |
| K.B. | 7 | Congenital shortening | Transverse (second procedure) | | 3⅜ | 17 | 49 |
| P.B. | 7 | Congenital shortening | Oblique | 2½ | ⅝ | 2 | 11 |
| C.G. | 5½ | Congenital shortening | Oblique | 2⅝ | 1¼ | 16 | 69 |
| S.H. | 7 | Congenital shortening | Step-cut | 2¼ | 2⅜ | 7 | 78 |
| R.E. | 10½ | Congenital shortening | Transverse | 6½ | 3⅞ | 30 | 116 |
| M.B. | 11 | Congenital shortening | Oblique | 5 | 2 | 10 | 33 |
| J.B. | 8¾ | Poliomyelitis | Transverse | 1½ | 1⅝ | 11 | 57 |
| W.D. | 11 | Poliomyelitis | Transverse | 1¾ | 1⅜ | 4 | 12 |
| L.T. | 11 | Poliomyelitis | Step-cut | 2¼ | 1⅞ | 6½ | 60 |
| D.M. | 11 | Poliomyelitis | Step-cut | 2¼ | 2¼ | 10 | 16 |
| I.L. | 13½ | Poliomyelitis | Oblique | 3 | 3⅜ | 11 | 42 |
| G.G. | 10 | Tuberculosis of hip | Step-cut (first procedure) | 3¼ | 1½ | at surgery | 32 |
| G.G. | | Tuberculosis of hip | Transverse (second procedure) | 5 | 4¼ | 18 | 68 |
| G.G. | | Tuberculosis of hip | Transverse (third procedure) | 1¾ | 1 | 4 | 31 |
| P.E. | 12 | Tuberculosis of hip | Step-cut | 4 | 2⅜ | 11 | 35 |
| E.H. | 15 | Tuberculosis of ankle | Step-cut | 1¼ | 1½ | 4 | 68 |
| S.Y. | 12½ | Tuberculosis of hip | Oblique | 2 | 2 | 2 | 26 |
| I.S. | 12¼ | Septic hip | Step-cut | 4½ | 3⅝ | 16 | 87 |
| W.B. | 9 | Congenital dislocation of hip | Transverse | 1¼ | 1 | 2 | 25 |
| J.S. | 11 | Congenital dislocation of hip | Transverse | 1½ | 1⅝ | 11 | 37 |
| J.D. | 13½ | Osteogenesis imperfecta | Step-cut | 3 | 3 | 9 | 130 |

patients, tuberculosis in four patients, septic hip in one patient, congenital dislocations of the hip in two patients, and osteogenesis imperfecta in one patient, making a total of twenty (Table I).

The types of osteotomy performed were: transverse in nine operations, step-cut in nine operations, and oblique in five operations. The amount of the lengthening of the femur gained through these operations varied from three-eighths of an inch to four and one-quarter inches (Table II). In seven patients, there was a gain of three inches or more in length, while in five others the gain was between two and three inches. There were two failures in patients in whom less than one inch of length was gained following the osteotomy. In one of these (K. B.), the failure was corrected and a lengthening of three and three-eighths inches was obtained by a second operation in which a new osteotomy was made over the same intramedullary rod.

TABLE II

| Patient | Type of Osteotomy | Etiology of Shortening | Length Gained (*Inches*) |
|---|---|---|---|
| G.G. | Transverse (second lengthening) | Tuberculosis of hip | 4¼ |
| G.G. | Transverse (third lengthening) | | 1 |
| I.M. | Transverse | Congenital shortening | 3⅞ |
| W.B. | Transverse | Congenital dislocation hip | 1 |
| J.S. | Transverse | Congenital dislocation hip | 1⅝ |
| W.D. | Transverse | Poliomyelitis | 1⅜ |
| K.B. | Transverse and graft (second lengthening) | Congenital shortening | 3⅜ |
| R.E. | Transverse and graft | Congenital shortening | 3⅞ |
| J.B. | Transverse and graft | Poliomyelitis | 1⅝ |
| G.G. | Step-cut (first lengthening) | Tuberculosis of hip | 1½ |
| K.B. | Step-cut (first lengthening) | Congenital shortening | ⅜ |
| L.T. | Step-cut | Poliomyelitis | 1⅞ |
| D.M. | Step-cut | Poliomyelitis | 2¼ |
| P.E. | Step-cut and graft | Tuberculosis of hip | 2⅜ |
| E.H. | Step-cut and graft | Tuberculosis of ankle | 1½ |
| J.D. | Step-cut and graft | Osteogenesis imperfecta | 3 |
| I.S. | Step-cut and graft | Septic hip | 3⅝ |
| S.H. | Step-cut and graft | Congenital shortening | 2⅜ |
| I.L. | Oblique | Poliomyelitis | 3⅜ |
| S.Y. | Oblique | Tuberculosis of hip | 2 |
| P.B. | Oblique | Congenital shortening | ⅝ |
| M.B. | Oblique and graft | Congenital shortening | 2 |
| C.G. | Oblique and graft | Congenital shortening | 1¼ |

The greatest lengthening obtained by a single operation amounted to four and one-quarter inches after a transverse osteotomy.

The number of weeks required for the lengthening varied from three to thirty, although the lengthening procedure was continued past the eighteenth week in only two patients. With the exclusion of the two patients in whom failure was reported and one patient in whom one and one-half inches was immediately obtained at the time of the surgery, the average time required for the lengthening was about eleven weeks.

In thirteen of the twenty-three operations, union of the bone occurred in an average of thirty-two weeks with the total elapsed time varying from three weeks for the patient who gained only three-eighths of an inch to sixty-eight weeks for the patient who gained four and one-half inches. The type of the osteotomy did not seem to be of any significance with respect to the time required for the appearance of bony union at the osteotomy site (Figs. 6-A through 6-D, 7-A and 7-B, 8-A through 8-C, and 9-A through 9-E).

After ten of the osteotomies, one or more bone grafting procedures were necessary to obtain bony union. The average time required for the union of the bone in this group of patients, with secondary bone-grafting operations, was seventy-two weeks. In this group of patients, it was also noted that the type of the osteotomy employed did not influence the time required for the union to occur (Figs. 9-A through 9-E). All of the bone-grafting operations were performed as secondary procedures because of delayed union since intentionally no grafts had been used at the time of the primary operation.

FIG. 9-A

FIG. 9-B

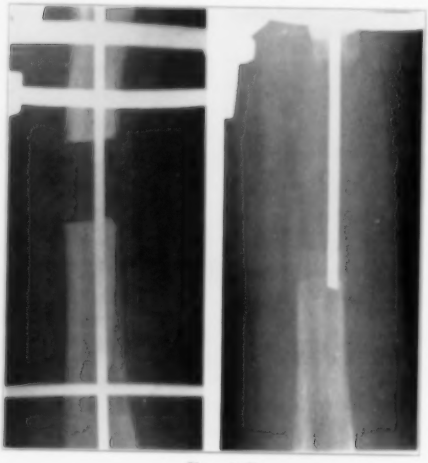


FIG. 9-C

FIG. 9-E

FIG. 9-D

Fig. 9-A: Patient K. B. Preoperative x-ray of congenital shortening of left femur to three and a half inches.

Fig. 9-B: X-ray made four weeks after the first operation shows the failure to gain length by step-cut osteotomy followed by simple traction on a pin through the distal end of the femur. The force of the traction without countertraction caused distraction of the hip joint.

Fig. 9-C: X-rays made one month and three and a half months after second lengthening procedure show the progress in gaining three and three-eighths inches length after transverse osteotomy and use of distraction apparatus.

Fig. 9-D: X-rays made after bone-grafting operations. The view on the left was made three months after implantation of a cancellous bone-bank graft. This graft was absorbed. The view on the right was made four days after a cortical bone-bank graft had been inserted.

Fig. 9-E: X-rays made two years and three months after the cortical bone-bank graft show three and one-quarter inches of lengthening and complete healing.

This series is too small to analyze statistically; however, the whole of our clinical experience with femoral lengthening done as described shows that there is a direct relationship between the length obtained and the time required for union. The greater the length obtained, the longer the time required for the union. It is also seen that the greatest number of bone grafts was necessary in the patients in whom the amount of lengthening

FIG. 10-A

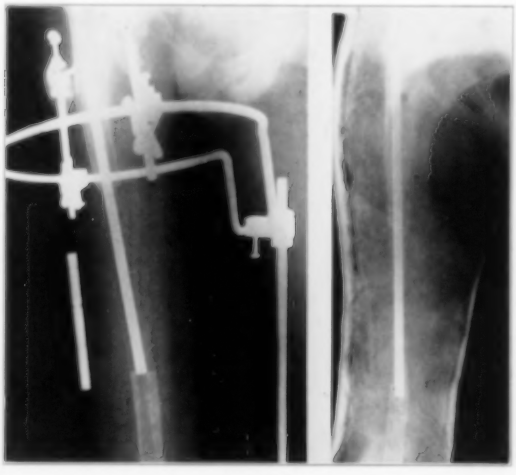


FIG. 10-B

Fig. 10-A: Roentgenogram five months after resection of a one and one-half inch segment of the right femur and immediate transfer of this to the left femur into a step-cut osteotomy. This discrepancy in limb-length was a complication of tuberculosis of the right hip with complete cessation of growth of the distal femoral and the proximal tibial epiphyses.

Fig. 10-B: Roentgenograms show the results eighteen weeks and thirty weeks after the second lengthening operation, a transverse osteotomy which was performed over the same intramedullary rod.

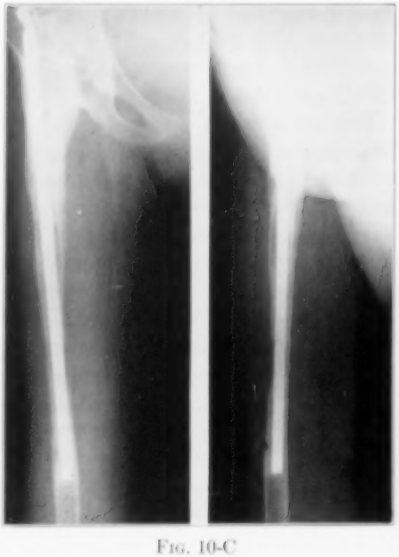


FIG. 10-C

FIG. 10-D

Fig. 10-C: Ten months after the second osteotomy the four and one-quarter inch defect was partially filled in and no bone-grafting had been necessary.

Fig. 10-D: Results ten weeks and seven months after the third osteotomy procedure, also a transverse osteotomy which was performed over the same intramedullary rod.

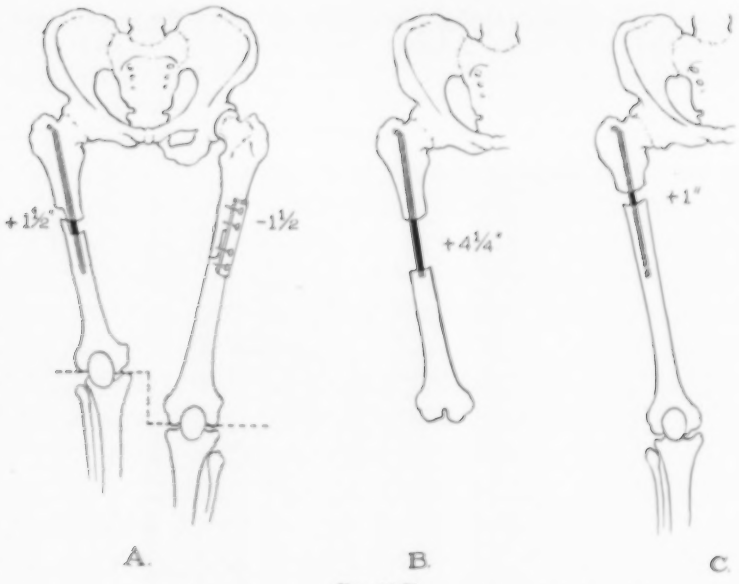



FIG. 10-E

Recapitulation of procedures performed in limb-length equalizing operations: (*A*) step-cut osteotomy of right femur with interposition of a one and one-half inch fragment from left femur which had been shortened by oblique-step osteotomy; (*B*) transverse osteotomy and traction-countertraction resulted in a four and one-quarter inch gain in length; (*C*) final gain of one more inch after a third osteotomy, again a transverse osteotomy.

had been greatest. The etiology of the shortening of the bone, however, did not seem to have any effect upon the time required for the union of the bone. Those patients in whom the shortening was due to a congenital cause seemed to have a chance for union equal to that demonstrated in the patients whose bone shortening was of an acquired nature.

The maximum correction achieved in these patients with limb-length inequality was a total of eight and one-fourth inches in a patient (G. G.) with tuberculosis of the hip and with complete cessation of growth of the distal epiphysis of the femur and the proximal epiphysis of the tibia from compression. This equalization was accomplished through a series of three femoral-lengthening operations on the right femur and a femoral-shortening operation on the left femur. At the first operation, a one and one-half inch segment was removed from the longer femur and was immediately inserted between the distracted fragments of the short femur; an intramedullary rod was inserted to hold the fragments in place (Fig. 10-A). The procedure resulted in an arterial spasm which required stripping of the femoral artery before the peripheral circulation was restored. However, the net gain toward equality of limb-length was three inches and this was maintained. Fourteen months later, a transverse osteotomy was performed over the same intramedullary rod and four and one-quarter inches of lengthening was produced by means of traction on the distal fragment of the short femur (Figs. 10-B and 10-C). A third osteotomy was performed over the intramedullary rod fourteen months after the second operation, and one and three-quarter inches was gained by traction; however, early removal of the traction pin resulted in a loss of three-quarters of an inch so that the net gain by this last procedure was only one inch (Fig. 10-D), and the total gain toward limb-length equality was eight and one-half inches (Figs. 10-E and 10-F).

## COMPLICATIONS

All surgeons who have performed operations for the lengthening of the long bones

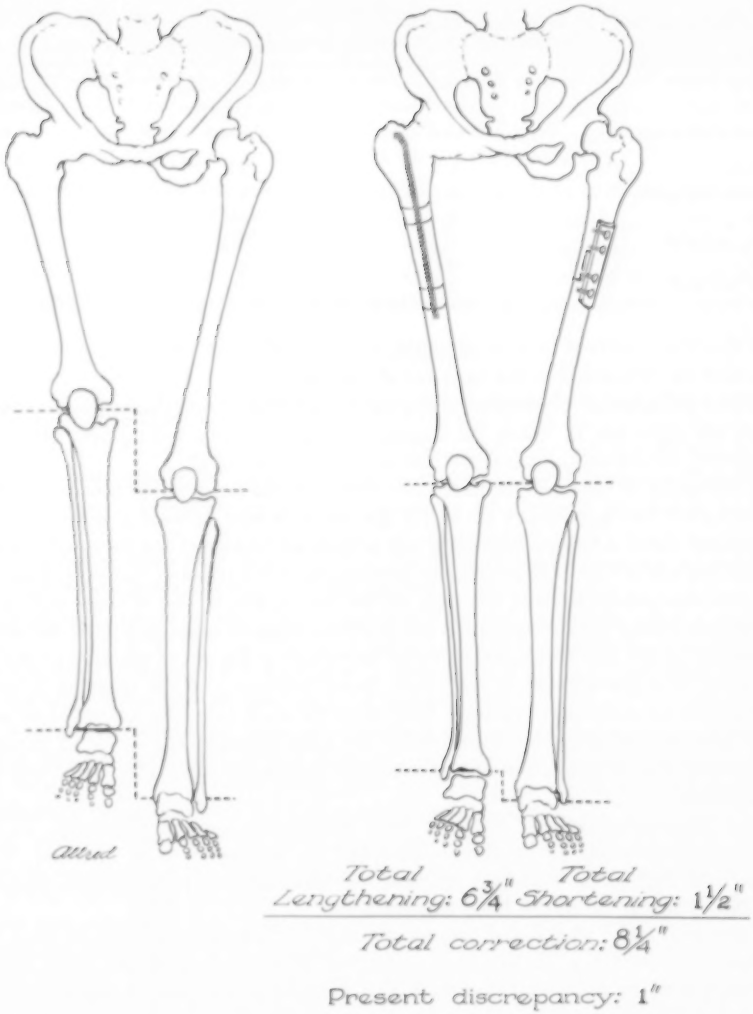



FIG. 10-F

Summary of correction of limb-length discrepancy by a combination of repeated femoral-lengthening operations and a femoral-shortening operation.

have had firsthand experience with the complications which may result. The authors are not exceptional in this respect; although the operations had been carefully planned and executed, some complication accompanied each of the operations reported. Fortunately, no deaths occurred and none of the extremities were lost, but some of the complications were of a serious nature.

Only two complications occurred immediately after the operation. These were the arterial spasm mentioned before and a peroneal palsy that was noticed on the day following the operation. No infections resulted from the primary operation.

The only wound infections that did develop appeared in three patients after the implantation of the bone grafts from the bone bank in secondary operations which were performed to promote union of the bone fragments. All of these infections were delayed and did not occur until long after the secondary operations. Infection along the tract of

TABLE III

SUMMARY OF RESULTS WITH VARIOUS PROCEDURES

| Type of Osteotomy | Number of Cases | Average Gain in Length (*Inches*) | Average Period Before Union (*Weeks*) |
|---|---|---|---|
| Transverse | 6 | 2¼ | 38 |
| Transverse and graft | 3 | 3 | 74 |
| Step-cut | 4 | 1½ | 29 |
| Step-cut and graft | 5 | 2½ | 80 |
| Oblique | 3 | 2 | 26 |
| Oblique and graft | 2 | 1⅝ | 51 |

one of the pins occurred in nine patients, but none of these infections were of a serious nature and all responded to the removal of the pin.

A late disturbance of circulation during the process of lengthening was noted in one patient, the same one in whom the vascular spasm had occurred earlier. This condition was relieved immediately by a reduction of the traction weight.

A late palsy of the peroneal nerve occurred in seven patients; in five it was transient, while in two it was permanent. In one of the patients who suffered a permanent palsy of the peroneal nerve, a triple arthrodesis was performed to correct the deformity of the foot.

Deformities of the knee joint have been encountered in seven patients. Five patients had a posterior subluxation of the tibia on the femur, and in two of these patients it was necessary to release the soft tissues in the popliteal space in order to correct the deformity. Subluxation in the other two patients was corrected by the use of traction in one and the application of a plaster cast in the other. Some limitation of the range of knee motion resulted from all of the subluxations. Four other patients have also exhibited some limitation of knee motion after the operation for the lengthening of the femur. A minor degree of instability due to relaxation of the collateral ligaments of the knee joint was noted in four patients.

The intramedullary rod has also been responsible for complications. In four instances, the rod migrated proximally and had to be reinserted or replaced. Two rods became bent during the time that traction was being applied to the femur, and one fractured before the union of the bone was complete.

Fractures of the lengthened femora occurred in four patients. One of these patients sustained two fractures, on separate occasions, after healing of the bone, which had been lengthened by step-cut osteotomy, and removal of the cast. A supracondylar fracture occurred eleven months after operation, a month after the cast had been removed. A transverse fracture occurred through the lengthened area three and one-half years postoperatively, a year after all support had been removed. The other three patients sustained one fracture each. In one, the distal tongue of a step-cut osteotomy was fractured four months after operation while the lengthening apparatus was still in place. Fracture occurred in another patient seven months after a step-cut osteotomy, three months after the removal of the lengthening apparatus and the application of a plaster cast. In the last patient, the fracture occurred through the lengthened area eight months after the transverse osteotomy, two months after healing and removal of the cast. All of the fractures healed without complication or undue difficulty.

The union of the osteotomized bone fragments was delayed in eleven patients. Ten of these patients had secondary bone-grafting operations which resulted in union, and a late union followed the application of a plaster cast in the eleventh patient. Eventually, there was union of the bone in all of the femora which had been lengthened.

In the review of the complications encountered in this group of operations, it was apparent that the employment of the intramedullary rod had eliminated the usual diffi-

culty of controlling the alignment of the osteotomized fragments. The number and the frequency of the complications which were associated with the unyielding soft tissues of the thigh indicate, however, that these complications still constitute the major problems encountered in the lengthening of the long bones. Much more attention must therefore be given to a study of the means by which these latter complications may be minimized or avoided.

The occurrence of so many complications might suggest that this operation should be condemned completely. However, the serious problem presented by the unusually short lower extremity demands that further and continued attention be given to its solution and to the elimination of the complications which occur in a procedure which otherwise satisfactorily achieves its aim of lengthening.

## SUMMARY AND CONCLUSIONS

1. The intramedullary rod has been used to control the alignment of the osteotomized fragments in twenty-three operations performed for the lengthening of the femur, and it has been found to be eminently satisfactory, eliminating many of the difficulties which were formerly encountered in maintaining the position of the osteotomized fragments.

2. In addition to the conventional osteotomies by step-cut or oblique section, a transverse osteotomy has been performed. The combination of the intramedullary rod and the transverse osteotomy has simplified the femoral-lengthening operation and has afforded the best means yet known for the control of the fragments.

3. A primary union of the bone fragments occurred as readily after a transverse osteotomy as it did after the other types of osteotomy which provide for a contact of the bone fragments throughout the lengthening procedure. This indicates that during its growth the bone callus may be stretched out in length.

4. A delayed union of the bone occurred with an undesirable frequency. From their experience with this series the authors could not determine the cause of the delayed union nor can they present any definite information concerning the optimum time for starting the lengthening procedure after the performance of the osteotomy.

5. It would appear that the more the bone is lengthened, the longer is the time required for the union of the fragments and the more likelihood there is of non-union.

6. While the etiology of the shortening has no bearing upon whether union of the fragments will occur or not, it does have some influence on the success of the procedure for lengthening. Shortening of an acquired nature responded more readily to the lengthening procedure than did that resulting from a congenital failure of the growth of the limb. It may be concluded, in the latter instance, that the soft tissues are structurally adapted to the shortened bone and therefore less elastic than those in the limb which has become shortened because of an acquired disturbance of its growth.

7. In addition to the complications involving the healing of the osteotomy, many other complications have occurred. While the intramedullary rod and the transverse osteotomy have simplified the operation, this method has not influenced the occurrence of the complications resulting from the resistance of soft tissues and the stretching of the vessels and the nerves of the thigh. Much more attention must be directed toward these problems in order to avert neurovascular complications and deformities of the knee joint.

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## DISCUSSION

Dr. T. Campbell Thompson, New York, N. Y.: When I was first asked to discuss this paper I declined because I did not want to disagree with my dear friend Tobby Bost. Unfortunately, I do have to disagree and hope he will forgive me. A number of years ago we studied very carefully the results of equalization of limb lengths[a,b]. All of the methods used resulted in some complications; none should be undertaken, therefore, without very careful consideration.

I recently saw a patient who had had an epiphysiodesis of the lower end of the femur at the age of six. The operation had been done because of a congenital shortening of two inches in the other extremity. When the patient was nine years old, the limb operated on was one and one half inches shorter than the other, and the discrepancy was increasing. Obviously the operation was undertaken without due consideration and was done at much too early an age.

The number of complications that followed lengthening of either the femur or the tibia were such that limb lengthening was given up many years ago at the Hospital for Special Surgery. Arrest of growth in children and femoral shortening in adults have been continued. For gross shortening of an extremity, a Syme amputation with a good prosthesis is, in our opinion, the best procedure.

The introduction of the intramedullary nail seemed to provide a good way of maintaining alignment during lengthening or shortening of the femur. In eleven patients with shortening in whom an intramedullary rod was used so many more complications resulted than occurred in the forty patients in whom oblique osteotomies were done that we have returned to the use of this method almost entirely[c]. [Slides were shown of the roentgenograms of the one patient in whom lengthening was attempted over an intramedullary rod.] This seemed to be an ideal case, for the limbs were normal, except for two and one-half inches difference in length. The femoral fragments failed to slide on the nail, and, after the removal of the nail, there was angulation. After the osteotomy had healed, an arrest of growth was done upon the other limb; we think the final result will be good. We did not, however, gain any length in the femur, and for some months we were quite unhappy.

When surgeons as capable as Dr. Bost and Dr. Larsen encounter complications, it should make the rest of us think a long time before electing to use this method when simpler ones are available.

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# Treatment of Low-Back and Sciatic Pain by the Injection of Hydrocortisone into Degenerated Intervertebral Discs *

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The degeneration of the intervertebral disc is an insidious process commencing in the second decade of life. The structural changes in the annulus fibrosus first appear as concentric fissures which do not communicate with the nucleus pulposus, a process which was described in detail by Hirsch and Schajowicz. The fibers of the annulus, however, also rupture radially from inside outward due to increase in intranuclear pressure.

Characteristically, a degenerated intervertebral disc may exist in a quiescent state for a long time and give promise of continuing in the subclinical state indefinitely, only to flare up into an acute phase either spontaneously or secondary to injury. Surgical exploration of the interspace during an attack usually demonstrates a swollen, bulging, soft disc; the posterior annulus, although thinned out to a varying degree, is usually found intact. Only rarely is there a complete breach and, consequently, it would seem that these degenerative changes frequently should be reversible.

The local anti-inflammatory action of hydrocortisone was well described by Hollander, and the value of the drug in reversing or blocking the inflammatory process in degenerative joint disease, tendonitis, tenosynovitis, and related conditions has been universally verified. The mechanism of this action is obscure, although the polymerization of the connective-tissue polysaccharides probably is facilitated in some way.

With these facts and experiences in mind, it was deduced that hydrocortisone should have a like beneficial effect when injected into the acutely swollen intervertebral disc, if the process had not become irreversible; that is, if complete rupture had not occurred.

Only one injection was made. The hydrocortisone solution and an iodopyracet solution were combined so that a nucleogram could be made at the same time that the therapeutic solution was injected. The nucleogram served a dual purpose; the immediate condition of the disc was determined and the nature of the ensuing clinical response to the hydrocortisone could be evaluated and related to the state of degeneration of the disc. The method of nucleography used is a modification of the technique described by Erlacher.

## TECHNIQUE

The patient lies in the flexed position on his side on the x-ray table and the disc under investigation is centered for a lateral roentgenogram. The disc is punctured by inserting a four-inch, 22-gauge, regional block needle through an anaesthetized area 1.5 centimeters lateral to the upper margin of the spinous process of the subjacent vertebra. In this way the ligamentum flavum is penetrated just medial to the facet and the dura is avoided in most instances. Entrance into the annulus fibrosus is accompanied by a sensation of rubbery resistance; after piercing the annulus, the needle is inserted about one more centimeter. The two lower lumbar discs are punctured routinely unless there is a definite reason for not puncturing one in particular and unless there is a reason to puncture one at a higher level. With the needles in place, a lateral roentgenogram is made and the accura-

* Read at the Annual Meeting of The American Orthopaedic Association at White Sulphur Springs, West Virginia, June 21, 1955.

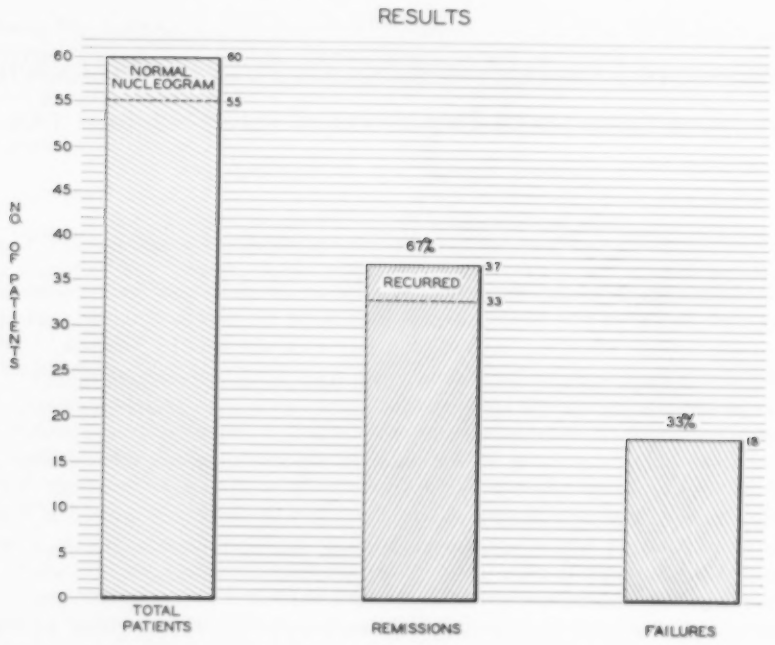


CHART I

The results of treatment expressed as percentage of patients with failure and with remission of symptoms.

cy of the position of the needles for injection is verified. The material to be injected is made up in a syringe by mixing three cubic centimeters of a 35 per cent solution of iodopyracet with one cubic centimeter of a solution containing fifty milligrams of hydrocortisone. Each interspace is injected under moderate pressure and the needles are withdrawn. Anteroposterior and lateral roentgenograms are then made. The capacity of each disc is noted, as well as the relative pain experienced at each injection. It is felt that these factors also aid in determining which one of the multiple degenerated discs has clinical significance. Trunk movements are made to help diffusion of the solution, the patient being allowed to use his own discretion regarding activity until the degree of response is determined.

## SELECTION OF CASES

This study is based on the results obtained with the first sixty patients successfully injected. In retrospect, it is difficult to analyze the choice of patients impartially, since only a small group suspected of having disc herniations was treated in this fashion. Thirty-six of the group were either in extreme pain and not responding to bed rest or had demonstrated a sudden progression in neurological symptoms. Seventeen had persistent or rapidly recurring symptoms in spite of bed rest, plaster-of-Paris jackets, back supports, and other conservative measures. Seven were injected for diagnostic purposes when the etiology was in doubt.

Five of the sixty patients had normal nucleograms, and none of these patients showed any improvement. The inadequacy of these patients as a control series is apparent; however, every effort has been made to eliminate subjective errors. None of the first twenty-five patients were aware that they were being exposed to anything other than a diagnostic test. Those who responded were completely surprised that the "test" had

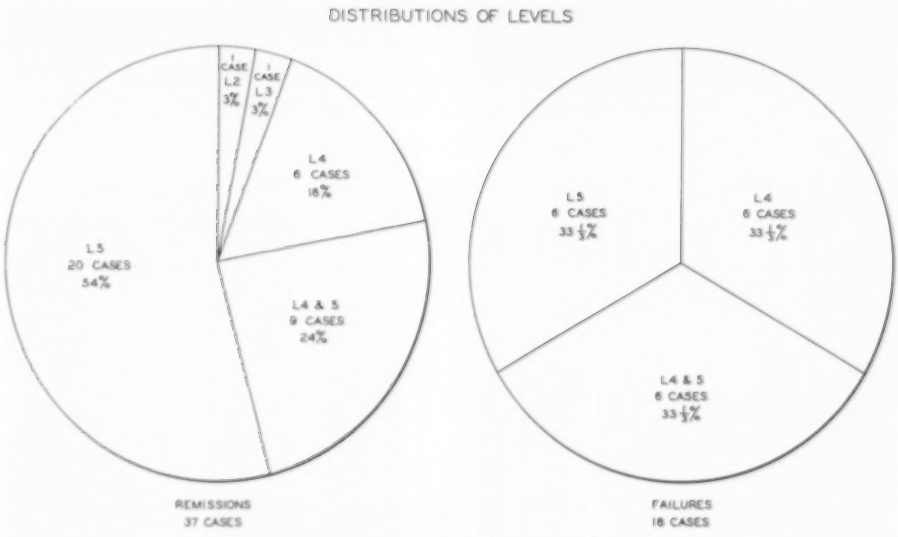
DISTRIBUTIONS OF LEVELS
1 CASE L2 3%
1 CASE L3 3%
L4 6 CASES 16%
L5 20 CASES 54%
L4 & 5 9 CASES 24%
REMISSIONS 37 CASES
L5 6 CASES 33⅓%
L4 6 CASES 33⅓%
L4 & 5 6 CASES 33⅓%
FAILURES 18 CASES

CHART II

The distribution of remissions and failures according to the level of involvement.

brought about an alleviation of symptoms. One patient with an obvious lesion of the fifth lumbar interspace was first injected at the level of the fourth disc. When no response occurred after five days of absolute bed rest, the fifth lumbar disc was injected and symptoms were relieved. Many of the patients were kept in bed from two to three weeks before the procedure and the effect of this pre-injection bed rest was noted. This precaution was taken to make sure that the effect of the injection and the post-injection bed rest had not coincided; thus it was ascertained that the relief of symptoms was the result of the injection and not of the conservative therapy. The injection solution used in all cases was the hydrocortisone-iodopyracet combination, and no discs were injected with iodopyracet alone. Thus in this series there is no data to prove that hydrocortisone alone was responsible for the results. However, in a personal communication, Dr. W. James Gardner of the Cleveland Clinic stated that he has never witnessed a beneficial effect from any of the several hundred nucleograms he has done in which only the iodopyracet solution was used.

## ANALYSIS OF RESULTS

The response of the fifty-five patients with pathological discs has been subjected to analysis (Chart I). Thirty-seven patients (67 per cent) had a rapid remission of symptoms. Subjective relief usually was first evident in four to six hours, and major discomfort had disappeared in twenty-four hours. Remissions have been permanent in thirty-three of these patients for a maximum follow-up period of eight months, while symptoms have recurred in four patients after periods of two weeks (one patient), two months (one patient), and three months (two patients).

There was no response to the injection in eighteen patients, 33 per cent of the total, with pathological lesions of the discs. The discs in sixteen of these have been explored surgically. In all but one patient, gross herniations were revealed with free cartilage either in the canal or directly under the posterior longitudinal ligament. The annulus fibrosus of the disc was intact in this patient; however, the nerve root was firmly adherent to the protrusion.

The response was evaluated on the basis of pain, spasm, scoliosis, sciatic irritability,

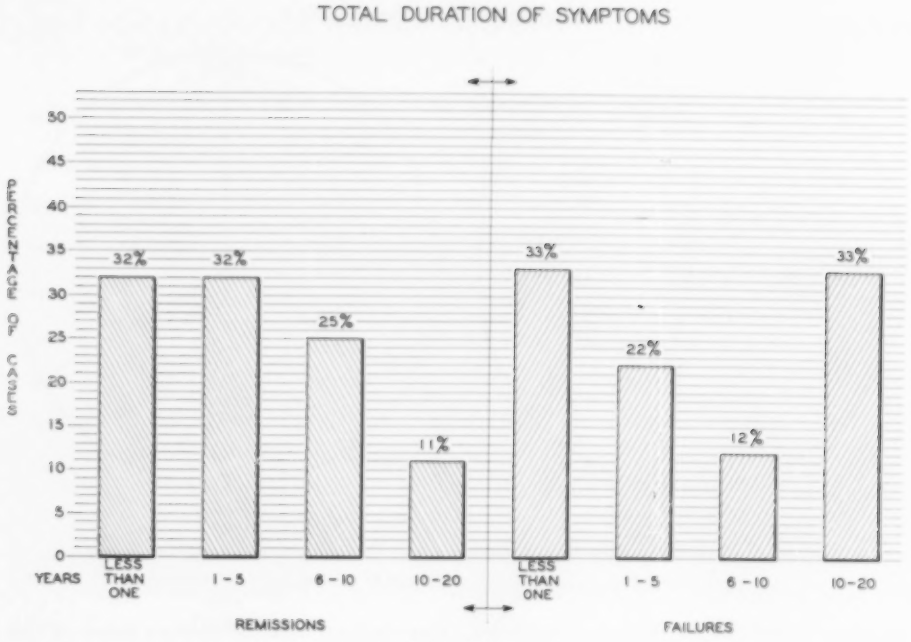


CHART III

The correlation of the duration of symptoms and the results shows that the response is no better when symptoms are of shorter duration.

and neurological findings. According to these criteria, remission in thirty-two was considered complete, and five patients with remission of symptoms still had some degree of discomfort.

In the group with remission of symptoms, in fifteen of the nineteen patients who had demonstrated abnormal neurological findings a partial to complete reversal of these findings had occurred.

When a correlation is made between the interspace involved and the number of remissions obtained, it is found that 54 per cent of the lesions with remissions were at the lower level, 16 per cent were at the fourth interspace, and 24 per cent of the patients with remissions had degeneration in both. Remissions in lesions at the level of the second and third lumbar discs were demonstrated in one patient each. The lesions of the eighteen patients with failures were distributed equally among the fourth, the fifth, and the fourth and fifth lumbar discs.

There was no real correlation between the duration of symptoms and the response, although a slightly higher incidence of failures occurred in the group with the longest history (Chart III).

The after-care given the patient with remission of symptoms was similar to that given following an interval herniated disc. A back support was ordered if back fatigue occurred and postural exercises were begun as soon as symptoms had subsided.

Complications of the procedure were limited to mild headaches in fifteen patients.

## CASE REPORTS

The following case reports of some patients with typical responses are recorded so that the sequence of events may be visualized.

CASE 5. A mechanic, fifty-one years old, was first seen seven months ago complaining of severe pain in

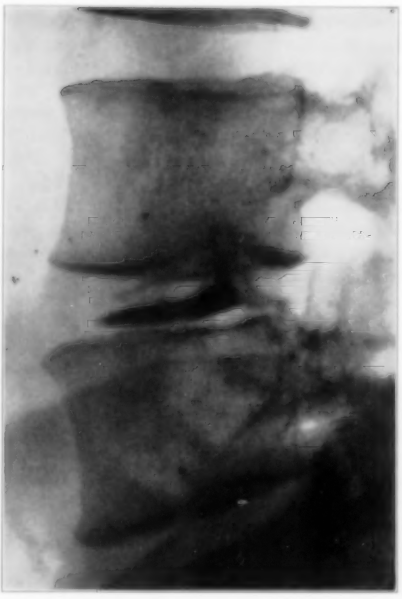

FIG. 1

FIG. 2

Fig. 1: First nucleogram in Case 8 shows the essentially normal pattern of the fourth lumbar disc.

Fig. 2: Second nucleogram in Case 8 shows the presence of a diffuse fragmentation with posterior protrusion of the fifth lumbar disc.

his right lower extremity. He gave a history of herpes zoster in the right flank four months previously; although he had recovered from this in three weeks, there was residual soreness in the right hip. Two weeks before he was first seen, the pain suddenly intensified and had rapidly become more severe, in spite of continuous bed rest at home. He came for examination after being unable to sleep for seventy-two hours. Examination revealed that the patient stood with a lumbar kyphosis, and that extension of the spine was impossible. He could bear very little weight on his right limb. Straight-leg-raising of 30 degrees was possible on the right and 70 degrees was possible on the left. The sciatic nerve was exquisitely tender along its entire course. The right ankle jerk was absent but no sensory changes were noted. He was hospitalized and could not sleep that night in spite of heavy doses of morphine.

On the next day, the fifth lumbar disc was injected with one and one-half cubic centimeters of the solution and augmentation of the symptoms ensued. The nucleograms demonstrated a diffuse fragmentation of the nucleus pulposus. Relief occurred within six hours and the patient had no trouble sleeping that night. The next day, walking was painless, and he was asymptomatic in forty-eight hours. The right ankle jerk was still absent. He returned to work and has had no recurrences. His ankle jerk returned two months after the injection, but is diminished. Postural exercises have been prescribed.

CASE 8. A stock clerk, thirty-four years old, was first seen six and one-half months ago complaining of pain in the low back and right lower extremity. His first symptoms had occurred three months before and had been relieved following chiropractic manipulation. The present attack had started two months previously and had become worse under similar treatment. He had been forced to stay in bed during the last five weeks. The constant pain in his right leg was accompanied by numbness and tingling.

Examination revealed that the patient stood with an extreme tilt to the right. Flexion to the left and extension were impossible. Straight-leg-raising of 10 degrees was possible on the right and 30 degrees was possible on the left. The right ankle jerk was absent, and there was sensory loss along the medial side of the right leg and foot. There was one-half-inch atrophy of the right calf. Routine roentgenograms were essentially negative.

The patient was hospitalized and, on the next day, the fourth lumbar disc was injected with one-half cubic centimeter of the iodopyracet-hydrocortisone solution. The nucleogram demonstrated a normal globular pattern of the disc (Fig. 1). The patient then had absolute bed rest for the next five days, but no improvement occurred.

The fifth lumbar disc was then injected with two cubic centimeters of the solution. The nucleogram

showed diffuse fragmentation of the nucleus pulposus with a posterior protrusion (Fig. 2). Relief was evident in four hours, and the patient was free of pain in forty-eight hours. In three weeks, the right ankle jerk and sensation had returned to normal, and he was instructed to resume work. He is on a postural exercise program.

Case 23. A forty-year-old auditor was first seen fifteen months ago complaining of back pain. He stated that he had had a severe attack six weeks before when out of town. Novocaine had been injected and he was treated by manipulation. He had not had any pain in the lower extremities at any time. The lumbar pain had disappeared gradually and the attack had almost subsided.

On examination some spasm was present in the lumbar muscles, and there was minimal limitation of extension. Straight-leg-raising of 70 degrees was possible bilaterally. The neurological examination was normal. It was suggested that the patient restrict his activity. On the next day, however, he was injured in an automobile accident. The patient now was obliged to stand bent forward and had severe pain in his left calf. He responded to bed rest and a back support and was given a program of exercise.

Eight months ago he suffered a relapse; this time he failed to respond to a similar regimen. Six months ago the fifth lumbar disc was injected with two cubic centimeters of the solution which caused a marked exacerbation of symptoms. The nucleogram demonstrated a complete break in the annulus with the dye diffusing downward and posteriorly in the sacral canal. The patient showed no improvement and a laminectomy was done a week later. The annulus was found to be perforated and a large mass of disc material was found lying free in the spinal canal. The extruded material was removed and the interspace was curetted. Recovery was uneventful and the patient has been asymptomatic since.

## SUMMARY

1. The effect of local instillation of hydrocortisone into the acutely swollen intervertebral disc was tested by combining the injection with a nucleogram.

2. The results, over a maximum follow-up period of eight months, are reported for the first sixty patients injected.

3. Nucleograms made of fifty-five patients demonstrated pathological lesions of the intervertebral discs. Thirty-seven patients (67 per cent) had rapid remission of symptoms after injection of hydrocortisone; eighteen (33 per cent) failed to respond.

4. Surgical exploration of the involved discs has been performed in sixteen of the eighteen failures and the discs in all cases demonstrated irreversible changes.

5. These results suggest a method of not only rapidly interrupting the course of an acute intervertebral disc herniation but also, more significantly, of demonstrating early in the course of the episode which discs are destined to require surgical intervention in spite of adequate conservative care. In this way, much of the morbidity and economic loss characteristic of these cases could probably be averted.

6. It is hoped that an investigation of the more fundamental causes of disc degeneration and of the mechanism of degeneration which underlie the empirical data presented here will help fill large gaps in our understanding of the pathogenesis and therapeutics of the degenerated and herniated intervertebral disc.

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## DISCUSSION

Dr. Robert A. Robinson, Baltimore, Maryland: Dr. Feffer has made a careful analysis of his cases to show the difference between deep segmental pain, which according to Kellgren [a, b] is characterized by hyperaesthesia and a vague pain outline, and true sciatic neuritis due to nerve-root compression which is characterized by muscle atrophy, diminished reflexes, well localized hypo-aesthesia, muscle weakness, and pain. The nucleograms generally reproduced the pain pattern of the chief complaint.

The fact is that in thirty-three patients of thirty-seven having signs of nerve-root compression, clinical remission of considerable duration followed the intervertebral-disc injections. In the other four patients

who also had immediate relief, the symptoms quickly recurred. The fluid injected into the nucleus of the disc deposited about twenty-five milligrams of hydrocortisone there. The longest follow-up was eight months, and the shortest was only three months.

Eighteen patients experienced no relief, and gross disc ruptures were subsequently found at operation in fifteen of these eighteen patients.

This might mean that, in the hydrocortisone-resistant cases, the nerve compression had been caused by an increased protrusion of disc material rather than simple oedema associated with a chronic protrusion. Actually, one can only theorize about the mechanism by which pain was relieved in the thirty-three patients who obtained relief for a significant time. The important fact is that, as shown by the clinical observation, pain relief was obtained. A longer follow-up and more clinical trials will undoubtedly be stimulated by these investigations by Dr. Feffer. The actual mechanism by which this pain relief was accomplished has yet to be exactly demonstrated. I think that Dr. Feffer is to be congratulated on a new approach to an ever-present clinical problem.

a. Kellgren, J. H.: Observations on Referred Pain Arising from Muscle. Clin. Science, **3**: 175–190, 1938.
b. Kellgren, J. H.: Some Painful Joint Conditions and their Relation to Osteo-arthritis. Clin. Science, **4**: 193–201, 1939.

Dr. Harold E. Crowe, Los Angeles, California: The facts presented by Dr. Feffer are very interesting, but I do not advocate this technique and I prefer not to use it. Herniation of the intervertebral disc is likely to be a sequel of injection of the disc. This occurred in a patient of mine who had had a lumbar puncture for a spinal anaesthesia. Prior to the spinal injection, the patient had never had any difficulty with his back, although he had worked hard at manual labor for many years. Surgical exploration revealed herniation of the disc which had been punctured for the anaesthesia.

Dr. J. Albert Key: This is a very important contribution to the treatment of disc degeneration, and we have already tried the technique described by Dr. Feffer. I think it is important to use a large needle; we tried Lindblom's method [a,b] with the very fine 26-gauge needle and had a great deal of difficulty inserting the needle. A larger needle makes the injection easier, and the risk of producing a herniation with the 22-gauge needle is negligible. This treatment may be the answer to those difficult cases of degenerated discs which we have been treating, with great reluctance, by surgical operation. We operate on these patients with reluctance because there seems to be no choice, and, in spite of what we do, they keep coming back. These are the patients who are not cured by postural exercises, who cannot be relieved by braces or bed rest. If we do not do something tangible for them, they will seek out the chiropractors and the osteopaths.

The discs that cause the most trouble, as a rule, are not those with a frank rupture. The greatest difficulty is encountered when, at operation, two discs show degeneration and swelling, although the nerve root is not necessarily inflamed; in these cases, we are at a loss to know what to do. Usually we excise the disc that appears to be most degenerated. We used to remove both discs, but we found that the end results were poorer, the more discs we took out. It is these patients, I believe, who will benefit from this important treatment. If Dr. Feffer is able to cure these patients by his method, it will be a great boon to orthopaedic surgery and to the patients of orthopaedic surgeons.

a. Lindblom, K.: Diagnostic Puncture of Intervertebral Disks in Sciatica. Acta Orthop. Scandinavica, **17**: 231–239, 1948.
b. Lindblom, K.: Technique and Results in Myelography and Disc Puncture. Acta Radiologica, **34**: 321–329, 1950.

Dr. Charles N. Pease, Chicago, Illinois: Twenty years ago, I published a report [a] on the injuries to the intervertebral disc as a result of lumbar puncture; I am greatly disappointed that, in the reports of nucleograms made by this technique, there was no mention of the possibility of a loss of nucleus pulposus through the aperture made in the disc by a 22-gauge needle. I have found that a 20-gauge needle *did* make enough space in the posterior portion of the annulus fibrosus, which is about one-third as thick as the anterior portion, to allow some of the material of the nucleus pulposus to escape. I believe that Dr. Feffer should review those so-called normal nucleograms; I am quite sure that he will find degenerated discs which, prior to the injection, were normal.

a. Pease, C. N.: Injuries to the Vertebrae and Intervertebral Disks Following Lumbar Puncture. Am. J. Dis. Child., **49**: 849–860, 1935.

Dr. Feffer: Before I answer Dr. Pease, I would like to speak of the solution itself. As I have explained, the iodopyracet and the hydrocortisone solution are put in the same syringe, and only one, dual-purpose injection is made. At my request, Dr. Erich Mosettig [c], the Chief Chemist of the National Institute of Arthritis and Metabolic Diseases of the National Institutes of Health, has tried to combine the hydrocortisone and iodopyracet under all conditions, and no interaction was ever demonstrated, so that the possibility of a chemical reaction was eliminated.

The problem of whether or not the disc puncture has caused damage has been much discussed since

Dr. Hirsch and his associates [b] first reported their findings by nucleography. I think the most adequate review of Dr. Pease's article was written by Dr. W. James Gardner and his colleagues [a] of the Cleveland Clinic. He reviewed reports of fifty-eight cases in which lumbar puncture was implicated in later disc degeneration. In reviewing the roentgenograms and the case histories, he found that most of these lumbar punctures had been done in cases of meningitis in order to inject antibiotics into the intrathecal space. He was reasonably certain that, in most of those cases, the subsequent complications were due to an interspace infection. In his own series of eighty-nine patients, one had an interspace infection, and the clinical course of the patient closely resembled that of the fifty-eight cases in the literature in which lumbar punctures were implicated in the disc degeneration. Of course, the merits of nucleography still may be disputed, but I think its worth has been adequately defended. In fact, it would seem almost indisputable that the risk of a laminectomy which may prove unnecessary is far greater than the risk of a disc puncture. Many successful disc punctures have been made. We have all used this technique, which is done under direct surgical approach, placing the 22-gauge needle into the annulus fibrosus, testing the disc for degeneration, and injecting the saline, with no ensuing disruption of the annulus fibrosus and no vertebral disruption.

Perhaps the placing of the needle itself could be further explained to make the technique perfectly clear. Usually I try to insert the needle as much laterally as possible just inside the facet, starting laterally a centimeter and a half away from the spinous process and somewhat caudally with respect to the involved disc. The needle is inserted at an angle, because the laminae, having a shingled formation, do not permit the needle to enter in the postero-anterior direction. If the needle is directed slightly upward so that the disc is entered at an angle just above the superior corner of the subjacent vertebra, there is a little more of an aperture and a slightly greater degree of latitude for the insertion of the needle. I have found this to be the easiest technique; Dr. Hirsch has probably done many more of these procedures than I have, and maybe he can make other recommendations. I have tried smaller needles and other techniques; they may be all right for nucleography, but if we want to combine nucleography with an injection treatment, the technique must be relatively simple. It must be remembered that these patients are apprehensive and in a great deal of pain. The total length of time in the x-ray room is less than half an hour, and frequently it is considerably less, and no exposure to fluoroscopic rays occurs. There were, however, some difficulties with the technique in the first half of the series; post-injection headaches were frequent, and the needle was inserted into the canal fairly often at first. But the time required for the procedure has been diminishing in a direct arithmetic ratio to the number of patients I have treated, so that in the last thirty or thirty-five cases there has been no trouble at all.

a. Gardner, W. J.; Wise, R. E.; Hughes, C. R.; O'Connell, F. B., Jr.; and Weiford, E. C.: X-Ray Visualization of the Intervertebral Disk. With a Consideration of the Morbidity of Disk Puncture. Arch. Surg., **64:** 355–364, 1952.

b. Hirsch, Carl, and Schajowicz, Fritz: Studies on Structural Changes in the Lumbar Annulus Fibrosus. Acta Orthop. Scandinavica, **22:** 184–231, 1953.

c. Mosettig, Erich: Personal communication.

*The question was asked, "In what position is the patient placed on the table?"*

Dr. Feffer: The patient lies on the table on his side, and I make only a lateral roentgenogram for localization. I have missed the disc in a few instances; because there was no antero-posterior roentgenogram by which to ascertain the position of the needle, the injection had been made with the needle placed alongside of the disc instead of penetrating it. After a while, however, one becomes skilled and learns to distinguish the feeling of the needle penetrating the disc. With experience, the angulation of the needle can be observed even in a lateral roentgenogram, so that one can verify that the needle has been placed properly, or that it has gone to the side of the disc. When placed properly, the needle is inside the facet and outside the dura.

*Question from the floor:* Does it make any difference on which side the injection is made with regard to the side involved by the sciatica? The nerve root at the disc level of the sciatica is very long and quite oedematous; it would seem that the needle might strike the root, creating additional trauma and more pain than is usual or justifiable.

Dr. Feffer: Because of the arrangement of our x-ray room, it is more convenient to have the patients lie on their left side. I therefore inject the solution into the right side of the disc, regardless of which side the sciatica involves.

# The Osteogenetic Phases of Regeneration of Bone

## A Historical and Experimental Study

BY DR. WOLFGANG AXHAUSEN, BERLIN, GERMANY

*From Chirurgischen Klinik am Städtischen Krankenhaus Moabit, Berlin*

*Translated by Jonathan Cohen, M.D., Boston, Massachusetts, and Henry Milch, M.D., New York, N. Y.*

During normal physiological renewal of the skeleton in adults, small amounts of bone are added continuously as the accretion component of internal remodeling. The accretion rate is markedly increased locally when repair of skeletal injury occurs. Even during the early scientific experiments in this field, there were two schools of thought. Were specialized cells, either those from the periosteum or those lining the bone trabeculae, the only antecedents of the tissue of accretion—that is, the bone-forming tissue of the repair process—or were *any* connective-tissue cells, when properly stimulated, transformed into osteogenic tissue?

### HISTORICAL REVIEW

In the latter part of the nineteenth century, this subject was taken up in the form of transplantation experiments and gave rise to a controversy between Ollier and Barth. Ollier [22], from data obtained experimentally in free-bone transplantation, maintained that transplants with periosteum intact could survive and grow in response to functional stress. Barth noted in transplants of calvarium without periosteum that the transplants became necrotic and were replaced by bone arising from the osteogenetic tissues of the graft bed. Georg Axhausen [2] confirmed Ollier's work, showing that while transplanted bony elements became necrotic, the periosteum survived and deposited bone. Then, through the authority of Lexer, there was general acceptance of Ollier's theory that in these transplants, the bone is produced by distinctive cells of the periosteum, bone marrow, and haversian canals, which were destined to become osteoblasts. Lexer [18, 19] stated that these cells were not histologically recognizable in the latent state but that they became so under proper stimulation. According to Lexer, the optimal stimuli were trauma and inflammation; in addition, according to G. Axhausen [3, 4], there must be included necrosis of bone which inevitably accompanies transplants, fractures, and other conditions in which bone nutrition is interrupted.

Following the observations of Barth and his emphasis on necrosis of the osseous transplants, Baschkirzew, Petrow, and Wereschinski found bone formation to occur after transplantation of bone fragments devoid of periosteum and marrow into soft tissues. Martin could observe no "resting osteoblasts" in adults and supported, as did these authors, the concept of osteogenesis by metaplasia of the cells of the recipient beds. This concept received further support from the experiments of Orell [23], who reported bone formation occurring after 100 days around transplants which had been prepared by boiling. Engström and Orell [12] noted similar results after fifty-three days with transplants which had been prepared by repeated freezing at −190 degrees centigrade. This led to the "inductive hypothesis",—that is, that the recipient bed, stimulated by an inductor substance in the transplant, is able to elaborate bone. Levander's experiments in which alcoholic extracts of bone were injected into rabbits to stimulate bone formation in the recipient tissues were widely regarded as confirming this hypothesis, especially after further confirmation by Annersten, Bertelsen, and Wachsmuth. Heinen, Dabbs, and Mason, however, demonstrated that in rabbits, alcohol alone could act as an inductor substance,

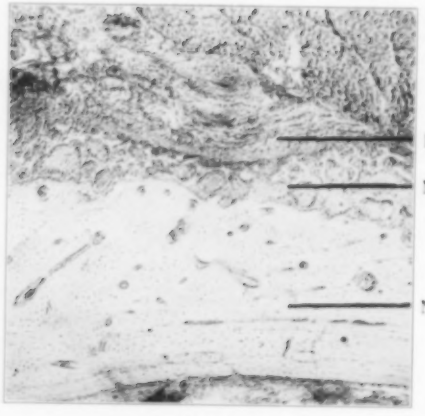


FIG. 1

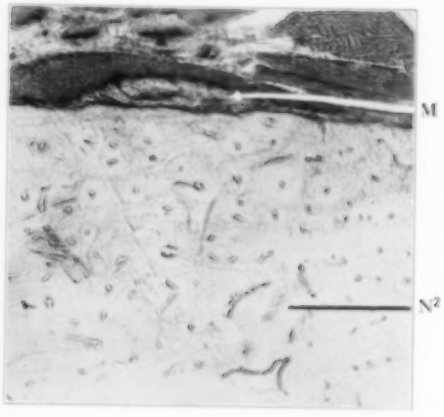


FIG. 2

Fig. 1: Photomicrograph (× 37, hematoxylin and eosin stain) of an eight-day-old autogenous transplant of tibial bone covered with periosteum (*P*). Subperiosteal new bone ($N^1$) in a lattice pattern is seen to be formed on the surface of the necrotic compact bone ($N^2$). (Reproduced by permission from "Experimenteller Untersuchungen zur Theorie der 'induzierten' Knochenneubildung (Levander)" by Wolfgang Axhausen in *Arch. f. Klin. Chir.*, **266**: 384, 1950.)

Fig. 2: Photomicrograph (× 37, hematoxylin and eosin stain) of an eight-day-old autogenous tibial bone without periosteum which had been transplanted into muscle of a dog. There is no new-bone formation. The tissues of the host (*M*) lie adjacent to the necrotic bone ($N^2$). (Reproduced by permission from "Experimenteller Untersuchungen zur Theorie der 'induzierten' Knochenneubildung (Levander)" by Wolfgang Axhausen in *Arch. f. Klin. Chir.*, **266**: 385, 1950.)

while Lindahl and Orell [20] and W. Axhausen [5, 6] showed that in other animals, alcoholic extracts of bone and alcohol-treated bone fragments were ineffective.

Numerous experimental studies have been devoted to new-bone formation by metaplasia in non-specific connective tissue under the influence of the epithelium of the urinary tract (Sacerdotti and Frattin, Huggins, Welcker [30, 31], and others), showing unequivocally that, in a suitable environment, connective-tissue cells can differentiate further into bone-forming tissue. However, the stimulant used in these experiments, the necrotic epithelium

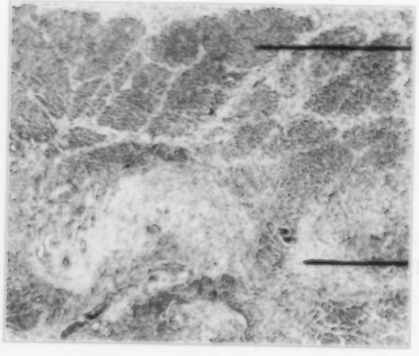


FIG. 3-A

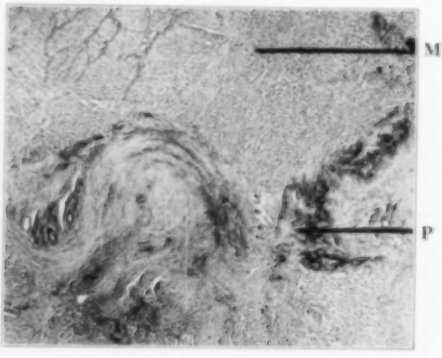


FIG. 3-B

Fig. 3-A: Photomicrograph (× 37, hematoxylin and eosin stain) showing cicatricial changes in a fourteen-day-old autogenous graft of tibial periosteum (*P*) which had been transplanted into muscle (*M*). There is no new-bone formation and the layers of the periosteum cannot be distinguished from each other. (Reproduced by permission from "Die Knochenbildungsfähigkeit der frei überpflanzten Knochenhaut" by Wolfgang Axhausen in *Zentralbl. f. Chir.*, **77**: 29, 1952.)

Fig. 3-B: Photomicrograph (× 37) of an adjacent section stained with orcein, showing clumping of the elastic fibers. (Reproduced by permission from "Die Knochenbildungsfähigkeit der frei überpflanzten Knochenhaut" by Wolfgang Axhausen in *Zentralbl. f. Chir.*, **77**: 29, 1952.)

TABLE I

AUTOGENOUS PERIOSTEUM TRANSPLANTED INTO MUSCLE

| Group Number * | Method of Transplantation | Number of Grafts | Number of Grafts with Osteogenesis |
|---|---|---|---|
| 1 | Loose implantation | 3 | 0 |
| 2 | Implantation on the stretch | 6 | 0 |
| 3 | Implantation on the stretch over tibial fragment | 7 | 3 |
| 4 | Implantation on the stretch under tibial fragment | 3 | 1 |
| 5 | Implantation on the stretch separated from bone fragment by muscle layer | 2 | 1 |

* The preparations in Group 4 were examined after twenty-one days, the others after fourteen days.

of the urinary tract, has no manifest relationship with the biological mechanism of physiological regeneration of bone.

Recently, Ray and his colleagues, working with tissue cultures of embryonic rat and adult human bone, refrigerated at −78 degrees centigrade, found that some of the cells survived, and, after a latent period of a few days, proliferated. They formed no bone but grew out as fibroblasts, which elaborated small amounts of matrix, some of which may have been osteoid.

To the present day, the exact roles of the periosteal cells and the bone matrix in the elaboration of bone after transplantation or during repair are still subject to speculation.

## EXPERIMENTAL MATERIAL

We have confirmed some of these earlier experiments in which active bone formation occurred following transplantation of free autogenous grafts into the soft tissues of adult dogs, provided that periosteum or marrow cells were part of the transplant. This was seen as early as the fourth day. When no periosteum or marrow was included in the transplant, new-bone formation was minimal and occurred only at a much later date. Resorption of the transplant often was delayed (Figs. 1 and 2).

FIG. 4-A

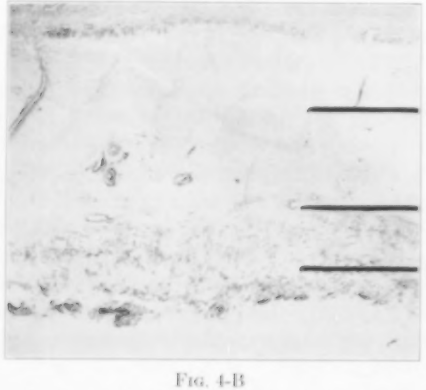


FIG. 4-B

Fig. 4-A: Photomicrograph (× 41, hematoxylin and eosin stain) of a fourteen-day-old autogenous graft of tibial periosteum which had been transplanted on the stretch into the muscle (*M*) of an adult dog. The adventitia (*A*) of the periosteum contain many vessels. The fibro-elastic layer (*F*) is broad. The individual layers of the periosteum are easily distinguishable and have evidently proliferated. No new-bone formation. (Reproduced by permission from "Die Knochenbildungsfähigkeit der frei überpflanzten Knochenhaut" by Wolfgang Axhausen in *Zentralbl. f. Chir.*, **77**:30, 1952.)

Fig. 4-B: Photomicrograph (× 41) of an adjacent section stained with resorcinol and fuchsin, showing the relaxed elastic fibers in an orderly arrangement. No new-bone formation is seen. (Reproduced by permission from "Die Knochenbildungsfähigkeit der frei überpflanzten Knochenhaut" by Wolfgang Axhausen in *Zentralbl. f. Chir.*, **77**:30, 1952.)

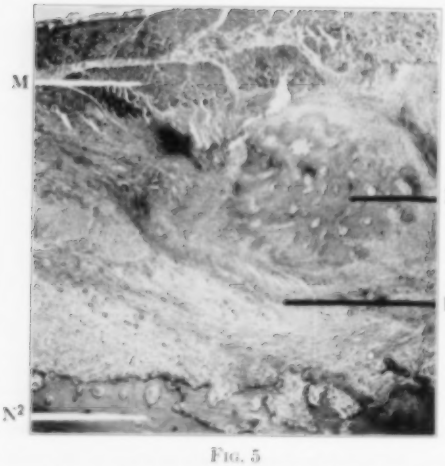


FIG. 5

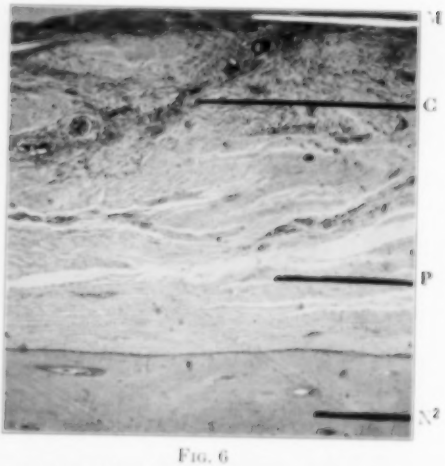


FIG. 6

Fig. 5: Photomicrograph (× 27, hematoxylin and eosin stain) of a twenty-one-day-old autogenous graft of periosteum (*P*) transplanted on the stretch underneath a fragment of compact bone in the muscle (*M*) of an adult dog. Resorption is evident in the necrotic cortical graft ($N^2$). There is active new-bone formation ($N^1$) consisting in a lattice-like osteophyte growing out of the periosteum in a direction away from the cortical graft. (Reproduced by permission from "Die Knochenbildungsfähigkeit der frei überpflanzten Knochenhaut" by Wolfgang Axhausen in *Zentralbl. f. Chir.*, **77**: 34, 1952.)

Fig. 6: Photomicrograph (× 51, hematoxylin and eosin stain) of a fourteen-day-old autogenous frozen graft of tibial bone with covering periosteum (*P*) transplanted into muscle (*M*) of an adult dog. The graft is dead; the periosteum is swollen and contains no stainable nuclei. There is invasion of the periosteum by connective-tissue cells (*C*) of the host, but no new-bone formation. (Reproduced by permission from "Die Knochenregeneration—ein Zweiphasisches Geschehen!" by Wolfgang Axhausen in *Zentralbl. f. Chir.*, **77**: 437, 1952.)

In experiments (Table I) in which autogenous periosteum alone was transplanted into muscle of adult dogs, the periosteum shrank because of its many elastic elements and underwent necrosis (Fig. 3). If the periosteum was carefully transplanted into the musculature and was kept on the stretch, extensive cicatricial changes were avoided (Fig. 4) but osteogenesis did not occur. When small pieces of cortical bone were implanted near the stretched periosteum, typical periosteal new-bone formation occurred in some cases (Fig. 5). This may be contrasted with G. Axhausen's findings that *unstretched* periosteal transplants which were in contact with fragments of bone did *not* evoke bone formation. This may be explained by better nutrition made possible through quicker diffusion and through ingrowth of vessels into the opened tissue spaces and vascular lumina of the graft.

Further experiments were done to determine whether any cells survived in grafts which had been prepared by freezing and whether the bone formation evoked by transplants of frozen periosteal bone was identical with that of fresh periosteal bone. A series of seven grafts, frozen at −35 degrees centigrade and kept at −15 degrees centigrade for twenty-four hours, were implanted into the soft tissues of dogs and were removed between the tenth and fifty-third postoperative day. The grafts removed between the tenth and fourteenth day after transplantation were completely necrotic. Not only the bone but also the periosteum contained no stainable nuclei; and the periosteal fibers were swollen and, in places, disintegrated. Vascular buds of the recipient bed infiltrated the bone canals and periosteum, but no new-bone formation was visible (Fig. 6). In the three preparations made from grafts removed after sixteen to thirty days, absorption of the bone of the graft was evident with resorption lacunae and uninuclear and multinuclear osteoclasts but no new-bone formation (Fig. 7).

The two transplants which were not removed for thirty days or longer presented a different appearance. The bone canals, which were widened by lacunar resorption, contained not only osteoclasts but also typical osteoblasts, and there were newly formed

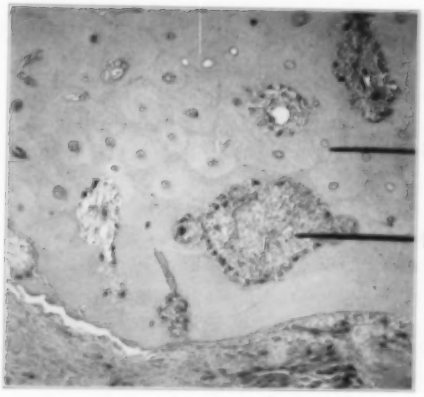


FIG. 7

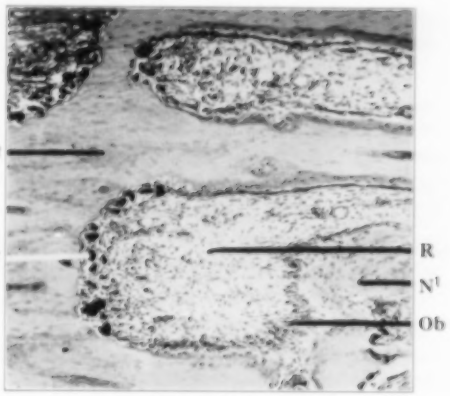


FIG. 8

Fig. 7: Photomicrograph (× 37, hematoxylin and eosin stain) of an eighteen-day-old autogenous frozen graft of tibial bone with covering periosteum transplanted into adult-dog muscle. The cortical fragment ($N^2$) is dead, but there is active lacunar resorption ($R$) with numerous osteoclasts present. (Reproduced by permission from 'Die Knochenregeneration—ein Zweiphasisches Geschehen!" by Wolfgang Axhausen in *Zentralbl. f. Chir.*, **77**: 438, 1952.)

Fig. 8: Photomicrograph (× 51, hematoxylin and eosin stain) of a thirty-day-old autogenous frozen graft of tibial bone with covering periosteum. The resorptive lacunae ($R$) have increased in size and, at their borders, osteoblasts ($Ob$) are laying down new bone ($N^1$) while the osteoclasts ($Oc$) continue to enlarge the lacunae in the necrotic cortical fragment ($N^2$). (Reproduced by permission from "Die Knochenregeneration—ein Zweiphasisches Geschehen!" by Wolfgang Axhausen in *Zentralbl. f. Chir.*, **77**: 439, 1952.)

seams of bone at the periphery of the canals. This was especially striking in those sections in which the areas of resorption had been cut longitudinally. While lacunar resorption by osteoclasts was actively proceeding deep in the resorption area, the more superficial parts of that area disclosed osteoblasts forming lining layers of osteoid (Fig. 8). In the older preparations, this rebuilding evidently occurred at a slower rate than in the fresh transplants studied earlier. In eight fresh cortical transplants of segments of rib or tibia with periosteum, the bone deposition was characterized by patterns of young, plexiform bone tissue spread on the surface of the graft. In the frozen-bone grafts, on the other hand, new-bone formation began in those areas in which osteoclasis had taken place. The areas in which the earliest lacunar resorption occurred were primarily peripheral, being found on the surfaces of the graft where the bone was somewhat splintered. It was especially striking that osteoclasis, and therefore new-bone formation, was particularly delayed on the periosteal side of the transplant. Here the necrotic periosteum walled off the graft from the recipient bed. In ten experiments with bone grafts, the organic components of which had been denatured by alcohol, an osteoclastic resorption could be demonstrated as early as four weeks. In these experiments no trace of bone regeneration was found as late as twelve weeks after transplantation.

## DISCUSSION

We may accept as established that, even in the adult, specific cells, specialized for the formation of bone, are present in the soft-tissue components of bone. Under the activating influence of necrotic bone substance, these cells differentiate into typical osteoblasts within several days and begin to form new bone. Disturbance of this process by stripping the soft tissue from the bone to which it belongs must be held responsible, in part, for mechanical injury to the cells. This is in accord with the assumption of Lexer that the determinative inner layer of periosteum is destroyed when it is freed from the underlying bone. It is possible too that activation of latent osteogenetic cells is seriously inhibited by loss of

organic union with the necrotic bone which they are potentially able to regenerate. The exact nature of the biological activation process is unknown.

The *osteoblast theory* and the *induction theory* thus have one point in common, namely the activating effects of necrotic bone. This influence on the preformed osteogenetic cells of the osteoblast theory can be accepted as certain. It remains to be determined what influence the necrotic bone exercises on non-specific connective-tissue cells. This influence is demonstrated in the systematic examination of bone transplants in which all cells are killed and in which only bone substance remains unaltered. The experiments of Engström and Orell, and Ray, Mosiman, and Schmidt, and our own experiments with frozen-bone transplants are the only pertinent evidence in this connection. Any other method of devitalization of tissue, such as treatment by chemicals, boiling, or autolysis [14, 15, 27], causes severe chemical changes in the bone substance. In the first two weeks following transplantation, frozen periosteal-bone grafts show all the histological signs of tissue necrosis. Later, however, osteogenetic cells appear within this tissue. What is the origin of these osteogenetic cells? We believe that transitory injury to the osteogenetic cells of the transplants, with later recovery, can be definitely excluded. Not only is such a restoration of specific cell activity after three weeks highly improbable, but the pattern of development of the osteogenesis is quite different from that of freshly implanted grafts. The experiments of Ray, Mosiman, and Schmidt in which some cells survived freezing to −78 degrees centigrade and grew in tissue culture, contradict our findings of complete devitalization of osteogenetic cells by freezing. This may be due to differences in the technique of freezing. Their demonstration of predominantly fibroblastic proliferation after a latent period is in accord with the concept that the sensitive, highly differentiated osteogenetic cells had died and a few relatively undifferentiated connective-tissue cells were able to survive. The evidence presented that osteoid was elaborated in tissue culture seems equivocal.

There is only one convincing explanation of the osteogenetic occurrences in our frozen grafts. The non-specific, pluri-potential connective-tissue cells of the host, develop into osteogenetic tissue under the influence of the transplanted necrotic bone substance. Simple contact of dead bone and young proliferating connective tissue is obviously insufficient to produce this. An osteoclastic resorption of adequate extent or adequate duration, or both, must occur. Similarly, the *determining* factor is not the bone mineral but rather the composition of the organic bone substance.

However, the local resorption of bone mineral may also play a certain role. It should be recalled that, over a protracted period of time, osteoclastic resorption of ashed and denatured bone substance may lead to bone formation. Implants of ashed-bone fragments (Wurm [33, 34]) and of boiled and macerated bone (Orell [23], Engström and Orell [12]) sometimes causes new-bone formation of small extent, but only after the lapse of more than 100 days. It is highly improbable that these observations possess any importance in the physiological regenerative processes of bone.

It must therefore be established that *bone regeneration takes place in two osteogenetic phases* which by proper experimental technique may be conclusively separated one from the other as regards the time of their appearance and their course of development. Normally, however, the first phase, which originates in pre-existing osteogenetic tissue and which possesses a markedly greater intensity, largely cloaks the later "non-specific" phase.

This knowledge enables us to combine the osteoblast theory and the induction theory in a single concept and thus to bury the old dualism. In the practice of surgery, the free autoplastic periosteal bone is undebatably superior for bone regeneration in the bridging of bone defects. When the periosteum (in which active osteogenesis originates) is separated from its underlying bone, a loss of the intensity of the first osteogenetic phase occurs. This phase cannot be dispensed with without detriment, a fact which has recently been demonstrated by Vainio in an impressive series of experiments.

The axiom of biphasic osteogenesis is valid not only for free-bone transplantation,

but also it is equally valid for bone regeneration in osseous wounds, in which traumatic avascular necrosis acts as a stimulus to the inception of the new-bone regeneration.

Other interesting points of view developed when this knowledge was directed to the problems in the use of "bone-bank bone", that is, when applied to the implantation of preserved homogenous bone as well as to heterogenous-bone grafts.

## SUMMARY

In past years, scientific discussion of the problem of causal osteogenesis was dominated by the conflict between the osteoblast theory and the induction theory. The work of Orell and Levander in particular contributed evidence to both theories. In the present series of experiments, the important osteogenetic significance of the soft-tissue components of bone—periosteum, marrow, and living cells of the bone canals—has been established anew. Even in adults, the latent osteogenetic cells were brought to proliferation and function within several days by the activating influence of bone necrosis.

To determine clearly the effect of non-specific connective tissue of bone substance *per se*, autogenous frozen-bone grafts covered with periosteum were transplanted in the dog. Up to the fourteenth day no evidence of bone formation could be found on histological examination. The histological appearance of necrosis of the periosteum is to be regarded as proof of the fact that the osteogenetic tissue was completely killed by freezing. Since sparse new-bone formation and delayed bone regeneration of the graft took place after some time (even up to fifty-three days), a transformation of the non-specific connective tissue of the host into osteogenetic tissue must have taken place. Consequently, the osteoblast and induction theories are combined into a unified concept.

Bone regeneration occurs in two osteogenetic phases,—the first and, physiologically, most important phase originates in the pre-existing specific cells and begins after several days. The inception of the second phase, however, originating in the non-specific connective tissue, requires several weeks. Both phases, nevertheless, are stimulated by the activating influence of the bone necrosis.

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# Homogenous Epiphyseal-Cartilage Grafts

## An Experimental Study

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This article reports the findings of an experiment in which epiphyseal cartilage from the long bones of newborn rabbits was transplanted into complete segmental bony defects made in the shaft of the radius of older actively growing rabbits. The study was undertaken because certain characteristics of epiphyseal cartilage indicate that it might provide a stimulus to ossification.

In the normal development of the skeleton, almost all the bones are first formed as hyaline cartilage which later undergoes systematic ossification. During this process, the cartilage cells hypertrophy and the lacunae break down; the cells then disappear as vascular, osteogenic buds invade the tissue. Although it was formerly believed that the role of the cartilage tissue in ossification was one of passive degeneration without any osteogenetic influence, there is considerable evidence to support the view that chondroblastic hypertrophy is a specific change, qualitatively different from the degeneration of small-cell cartilage or adult cartilage. Fell and Robison showed that areas of hypertrophied cartilage

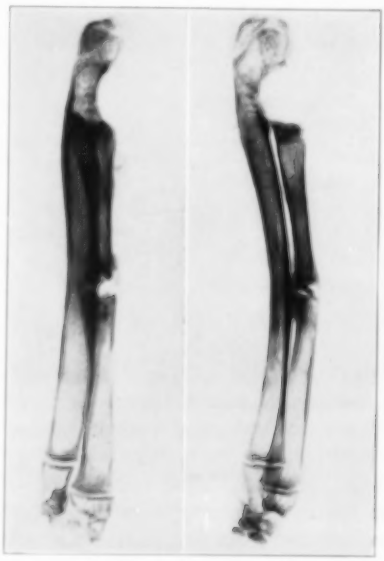

FIG. 1-A



FIG. 1-B

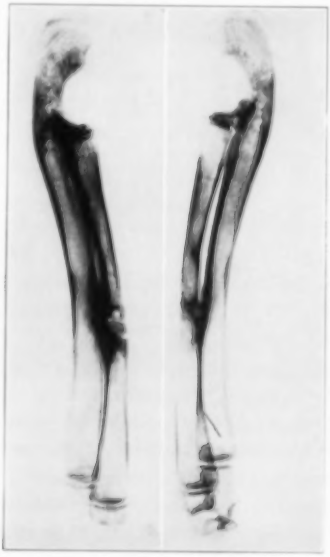

FIG. 2-A



FIG. 2-B

Fig. 1-A: Roentgenogram of the forelimb of an experimental rabbit, twenty-three days after transplantation of one cube of epiphyseal cartilage to a radial defect. Early evidence of new bone in the periphery of the cube is noted.

Fig. 1-B: Roentgenogram of a control limb, twenty-three days after operation. A segment of bone from the radius of another rabbit was used to fill the defect. The graft has been largely absorbed.

Fig. 2-A: Roentgenogram of a forelimb at thirty-three days. One cartilage cube was used in the radial defect. There is bony bridging of the radius on the ulnar side. Although there is apparent ossification of the cube, the microscopic section of this specimen (seen in Fig. 9) shows that the central portion of the cube is still largely cartilaginous.

Fig. 2-B: Roentgenogram of the control limb at thirty-three days. No material was implanted after the defect was made in the radius. Bony union is complete.

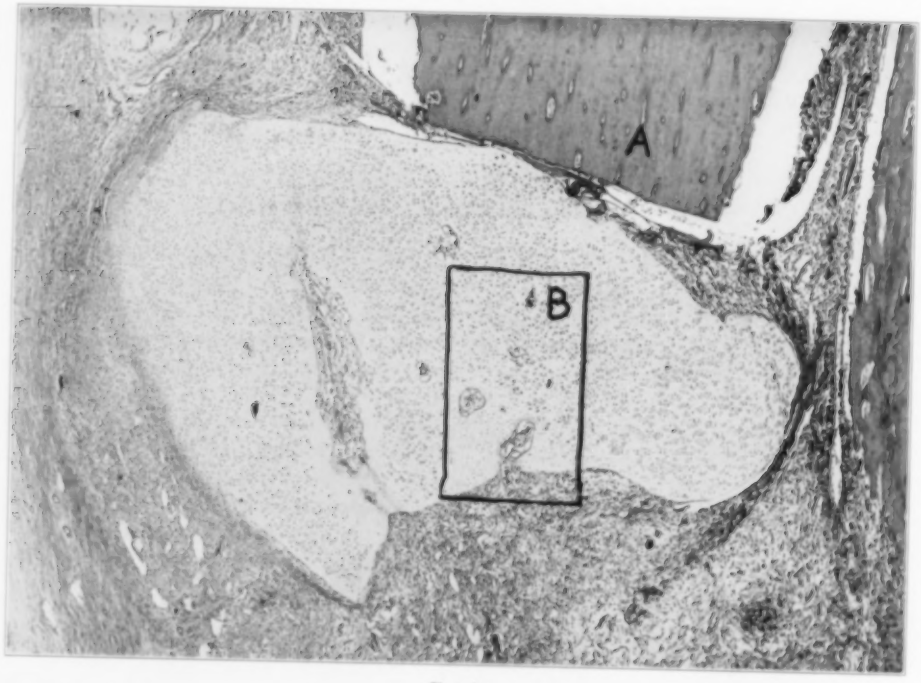


FIG. 3

Photomicrograph (× 36) of a section through the site of a bone defect, nine days after transplantation of two cubes of epiphyseal cartilage. The cartilage fragment in this section is in close contact with the cut surface of the radial shaft (*A*). A fibrous callus surrounds the fragment which shows several vascular channels. Early cellular hypertrophy and columnar formation is noted at the lower margin within the outlined rectangle (*B*). This area is seen in much greater magnification in Fig. 4.

developed in undifferentiated cartilage rudiments from fowl embryos cultivated *in vitro* only if destined to do so in normal development and only in that part of the rudiment where hypertrophy would have appeared *in vivo*. They also showed that phosphatase secretion by hypertrophic cartilage cells is consistently found only when the tissue culture is healthy.

A number of observers have reported that epiphyseal cartilage transplanted to various soft-tissue sites in animals of the same species forms bone. Lacroix performed transplantations of homogenous epiphyseal cartilage into the renal parenchyma of rabbits. Notable increase in the size of the grafts occurred. Lacroix postulated that epiphyseal cartilage cells contain an "organizer" for bone formation. Urist and McLean have also used the concept of induction to explain bone formation in soft tissues following implantation of bone or cartilage. In their studies, various tissues, including autogenous and homogenous grafts of epiphyseal and articular cartilage, were observed following transplantation to the anterior chamber of the eye of a rat. The epiphyseal cartilage grafts were isolated from neighboring bone by microdissection prior to transplantation. Eighteen autogenous transplants of epiphyseal cartilage were compared with seven homogenous grafts of epiphyseal cartilage. By the second or third week following transplantation, every cartilaginous transplant showed bone formation. There was no significant difference in the activity of autogenous and homogenous transplants. Growth and differentiation of the epiphyseal cartilage plate of the rat following its transplantation to the abdominal cavity and brain of another animal was noted by Nunnemacher.

Gordon and Warren obtained epiphyseal cartilage for homogenous transplantation

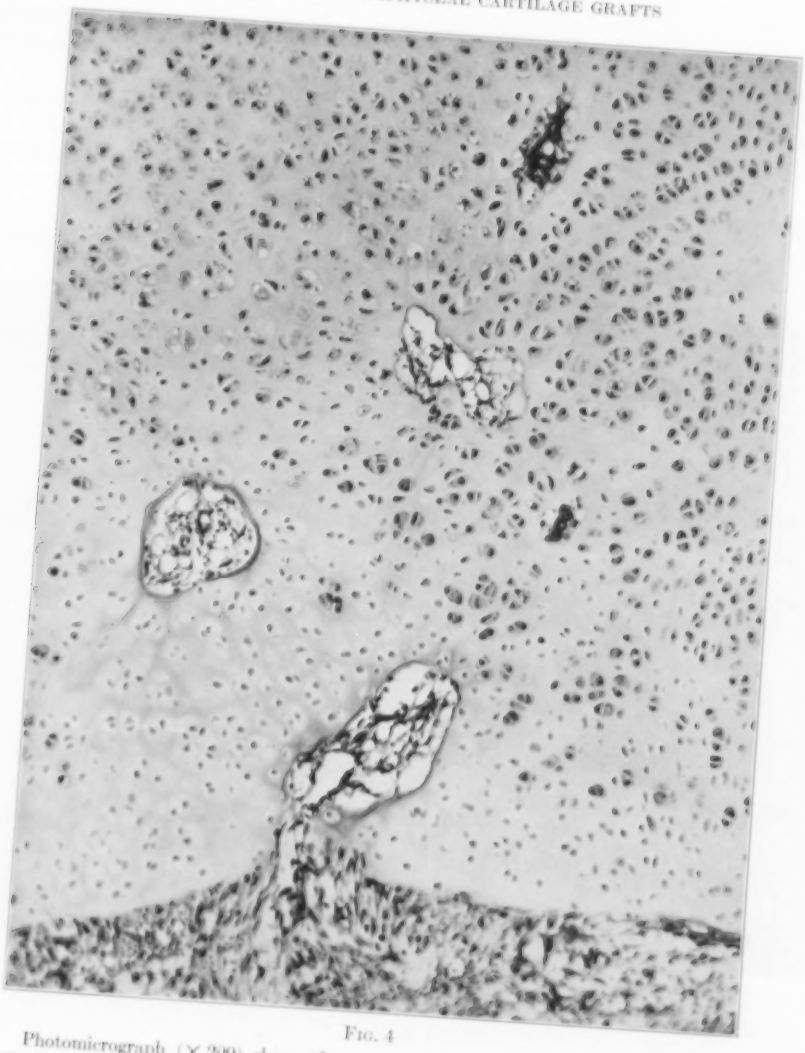

FIG. 4

Photomicrograph (×200) shows the area outlined in Fig. 3. Under considerably greater magnification, the early enlargement of cartilage cells with columnar formation between two vascular channels may be seen.

by excising the cartilaginous epiphyses of the long bones of rabbit foetuses. The epiphyseal ossification centers in the rabbit appear toward the end of the first week of life with the exception of the distal end of the femur which has a bony center at birth. The cartilage grafts were transplanted into an incomplete tangential defect made in a long bone of the forelimb of an adult rabbit. They reported that in these homogenous transplantations the cartilage cells underwent typical hypertrophy, "invasion", and replacement by bone. They concluded that the "propensity for growth" characteristic of epiphyseal cartilage was lost when it was transplanted, as no increase in the volume of the homogenous transplanted tissues was noted.

## EXPERIMENT

The procedure was performed on rabbits aged three to four months. A defect was made in the shaft of both radii by excising a complete segment measuring 0.4 centimeter in

length. On one side, the radial defect was filled with one or more fragments of epiphyseal cartilage which had been obtained directly from newborn rabbits less than three days old. Only epiphyses which were entirely cartilaginous were used.

The opposite forelimb was operated on as a control. One of the following measures was employed in this limb after the defect had been made in the radius: (1) The skin was simply sutured. (2) The complete segment of bone removed from the opposite radius was used as a free graft to fill the defect. (3) Cancellous bone from the pelves of freshly sacrificed newborn rabbits was placed in the defect.

All of the wounds were closed by approximating the skin edges with silk sutures. No

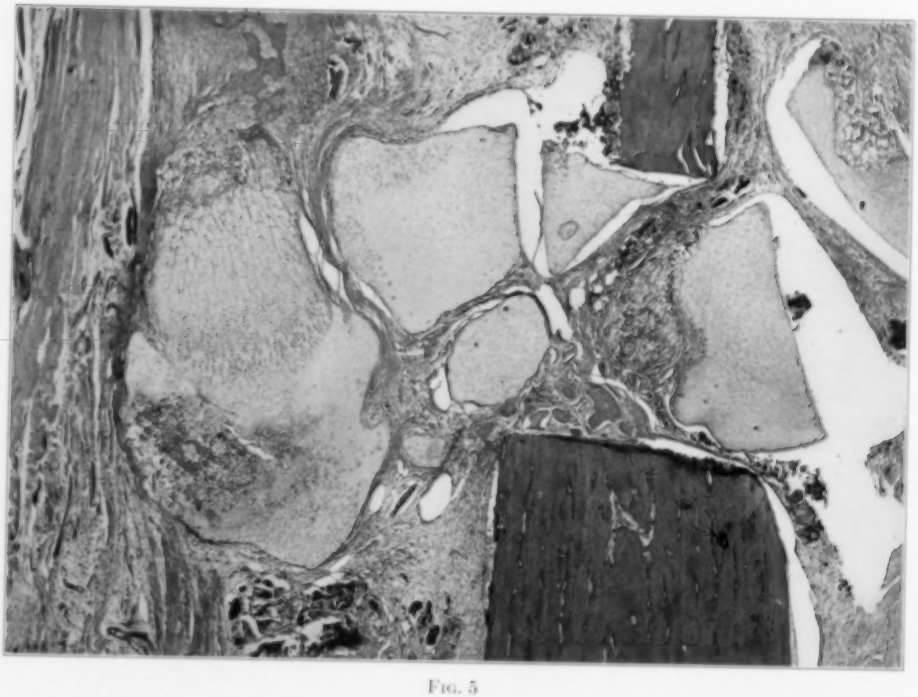

FIG. 5

Photomicrograph (× 28) made fourteen days after an operation in which multiple epiphyseal cartilage chips were transplanted to the bone defect. Primitive trabeculae are seen in the callus, bridging the bone ends. The cartilage chips incorporated in the callus show varying degrees of maturation changes. Endochondral ossification is highly active in two of the fragments.

immobilization was used. The animals were sacrificed and specimens were obtained for study at nine, fourteen, twenty-three, thirty-three, forty-two, and fifty-six days after operation.

Roentgenographic studies (Figs. 1-A through 2-B) of the limb specimens were made in two planes. Following formalin fixation and decalcification, the specimens were embedded in paraffin, sectioned, and stained with hematoxylin and eosin.

## RESULTS

Twenty-eight specimens were obtained from fourteen animals. One experimental limb and one control limb were excluded from the study because of wound suppuration. Two experimental limb specimens were obtained at each time interval with the exception of the fourteen-day period, when three specimens were available. Of the control limbs, two specimens were obtained at each of the indicated postoperative periods with these

FIG. 6

Photomicrograph (× 30) of an autogenous cortical bone graft fourteen days after operation on a control limb. The graft had been transplanted from the opposite radius to the bone defect. The graft is dead and absorption by invading marrow is advanced.

exceptions: only one specimen was obtained at the ninth day, and there were four specimens at fourteen days.

Comparison between the control and experimental limbs was made by gross, roentgenographic, and histological examination, and the rate and quality of callus formation were evaluated in the various specimens.

The number of specimens obtained is so small that generalizations based on the findings must be guarded. It was plainly evident, however, in the young rabbits employed in the experiment, that the bone defects in which no grafting material was placed were the first to demonstrate complete, mature, bony union. Clinical union of the fractures not grafted was evident in all animals by fourteen days, and, at this stage, numerous trabeculae bridging the gap in the radius were noted in all but one of the specimens on histological

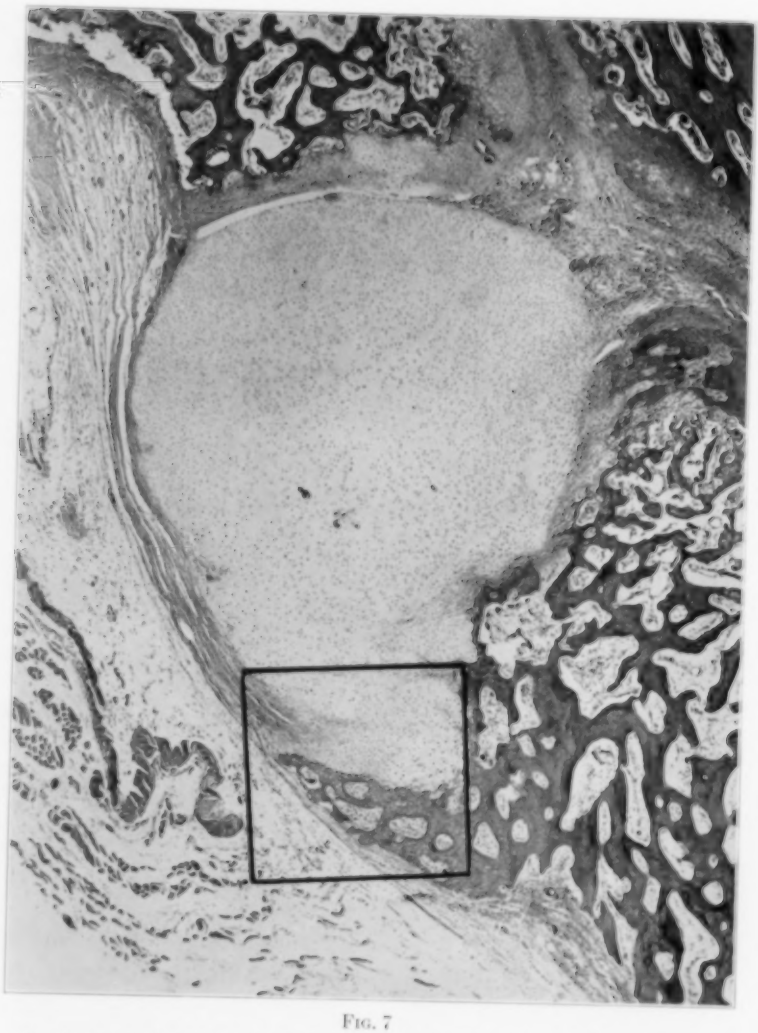

FIG. 7

Photomicrograph (× 33) of a section through the site of a bone defect, twenty-one days after transplantation of one cube of epiphyseal cartilage. In most of the graft, the cartilage cells are resting. A fibrous layer separates the transplant from the surrounding tissue on two sides. In the lower portion of the graft, in the area outlined, active replacement of cartilage by bone is noted.

study. However, roentgenographic evidence of union was seen for the first time in the specimens thirty-three days after operation (Figs. 2-A and 2-B).

In the fractures which had been grafted, bony union, demonstrable by microscopic and roentgenographic techniques, occurred at about the same rate, whether epiphyseal cartilage, iliac-bone chips, or a complete segment of radial bone had been used as grafting material. The bone grafts appeared necrotic in all sections and underwent progressive absorption (Fig. 6).

Most of the epiphyseal cartilage grafts demonstrated changes typical of endochondral ossification, but bone formation within the grafts was slow and irregular. Some of the cartilaginous fragments appeared inert, with no change apparent in the cellular structure fifty-six days after transplantation. Columnar cell formation and hypertrophy were seen

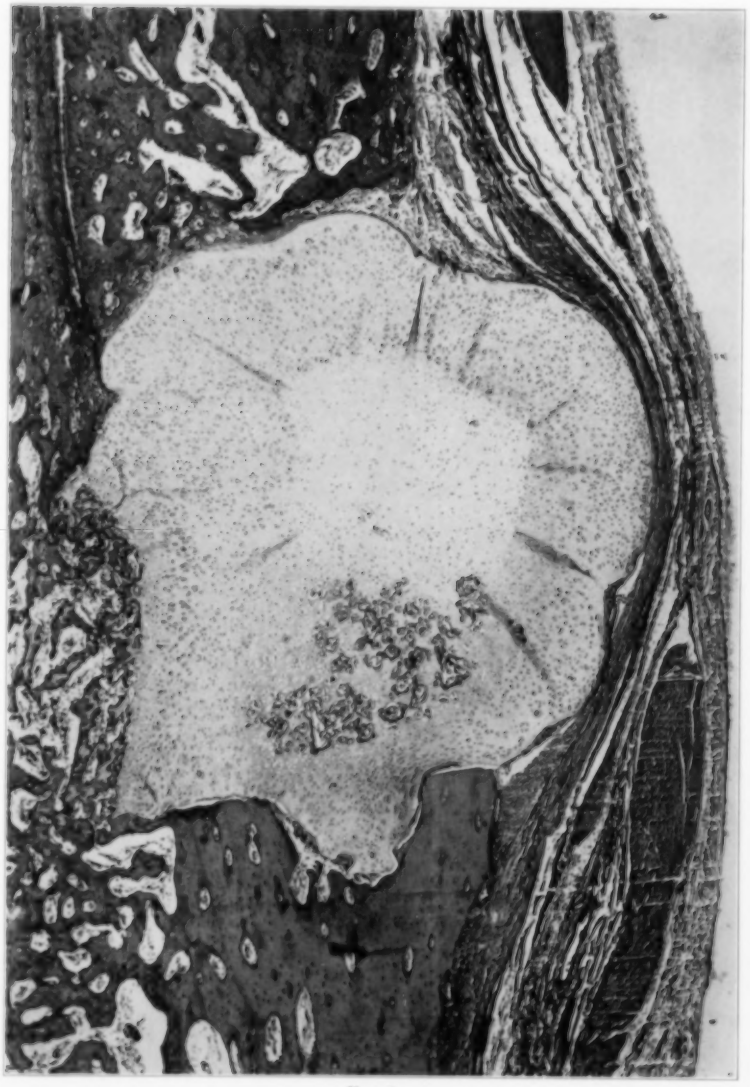

FIG. 8

Photomicrograph (× 35) of a section through the site of the bone defect, thirty-three days after transplantation of one cube of epiphyseal cartilage. Bony bridging of the defect has occurred along the ulnar side (on the left). There is endochondral ossification taking place at the face of the cube on this side. Irregular, primitive new-bone formation is seen in the depth of the cube.

in isolated areas of some cartilage fragments at nine days (Figs. 3 and 4). Some sections at fourteen days showed new bone within the cartilage graft (Fig. 5). The graft in this case, however, was walled off by fibrous tissue and the surrounding fracture callus contained numerous bridging trabeculae, far exceeding in volume the amount of endochondral bone. At twenty-three days, the roentgenograms of a radius in which a cartilage graft had been added show an apparent dead space at the site of the cartilage cube, confirming the impression gained from the slides that the graft acted more as an obstruction than an aid to union (Figs. 1-A and 1-B). At this stage (Fig. 7), and at thirty-three days (Figs. 8 and 9), and

FIG. 9

Photomicrograph (× 94) of a portion of the slide illustrated in Fig. 8, much enlarged, showing active endochondral ossification adjoining the bone end.

forty-two days, continued endochondral ossification in some areas was noted. Studies made at fifty-six days after operation (Fig. 10) demonstrated that resting cartilage remnants were still present, but they were difficult to find. Ossification in the typical endochondral pattern was still going on. At this stage, mature bony union was evident. None of the sections showed excessive bone formation which could be attributed to the presence of the epiphyseal cartilage. Sections made at twenty-one days and later illustrate the incorporation of small, inert cartilage fragments within newly formed bone.

Study of all sections disclosed that hypertrophy and columnar formation of cartilage cells appear simultaneously with the ingrowth of small blood vessels, and that definite calcification of the cartilage matrix is noted at this stage.

## DISCUSSION

The findings obtained in these experiments demonstrate that homogenous epiphyseal cartilage transplants can undergo the endochondral type of ossification when they bridge bony defects. Bone formation occurs so slowly, however, that the presence of the grafts does not accelerate but hinders the healing of the defect under optimal conditions for bone healing present in this experiment. Lacroix reported that, within four weeks, when cubes of epiphyseal cartilage were transplanted beneath the renal capsule of young rabbits, the

FIG. 10

Photomicrograph (× 40) of a section through the healed bone defect in a radius, fifty-six days after transplantation of multiple cartilage chips. The two pieces of cartilage, surrounded by a fibrous wall, are in contact with the outer surface of the radius. One of these cartilage fragments is inert, and most of the other fragment has undergone a primitive type of ossification.

cartilage increased enormously in size while forming bone. No significant increase in the size of the graft occurred in our experiment.

The rapid growth of cartilage grafts reported by Lacroix might be attributed to the excellent blood supply available to grafts in contact with the renal parenchyma.

Pereira and Dupertuis contended that osteochondromata might be produced by epiphyseal cartilage rests which had become lodged in the diaphysis. They based this view on the result of an experiment in which a small cartilage chip, excised from the proximal epiphyseal line of the humerus of a rabbit, was transplanted lower down on the shaft

in the same animal. In three out of nine rabbits so treated, large exostoses developed at the operative site in less than eight and a half weeks.

No cartilage or bone tumors were observed in the animals in our series. This group of experiments differs from those of Pereira and Dupertuis in at least one important respect: their findings were in autogenous transplants. This report deals only with homogenous transplants.

The fate of epiphyseal cartilage transplants in this experiment is essentially the same as in Gordon and Warren's experiment in which chips of epiphyseal cartilage were placed in an incomplete, tangential defect in the long bone of a rabbit. When a complete segment is removed from the shaft of a long bone, considerable local reaction results, much more than follows from a shallow, incomplete defect.

There is, too, an increased compression effect on the cartilage graft placed in a complete bone defect. These factors produced no visible special influence on the grafts.

## SUMMARY

1. Epiphyseal cartilage from newborn rabbits was transplanted into complete segmental bony defects made in the shaft of the radius of a young rabbit. The healing process was studied roentgenographically and histologically, the opposite forelimb having been used as a control.

2. Most of the cartilage transplants showed typical endochondral ossification.

3. The rate of bone formation in the grafted limb was slow when compared to the rate of healing in the control limb in which no grafting material was placed in the bony defect in the radius.

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# An Autoradiographic Study of Organically Bound Carbon-14 in Growing Epiphyseal Cartilage and Bone *

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This study was originally initiated in order to make a systematic autoradiographic comparison of the respective localizations of the bicarbonate ion labeled with radioactive carbon ($C^{14}$) and of the phosphate ion labeled with radioactive phosphorus ($P^{32}$) during the formation of *mineral elements* of growing bone. At the outset, however, it became evident that the $C^{14}$-labeled bicarbonate ion could participate in the *in vivo* synthesis of labeled organic tissue constituents, which could then be visualized autoradiographically in all of the organs and the tissues of the growing body.[18] Preliminary observations [16] further indicated that the organic matrices of the bones and the teeth were significantly labeled with $C^{14}$ derived from the bicarbonate ion.

Thus was presented the opportunity, previously lacking, to follow the formation of labeled organic bone matrix and to compare it with the formation of labeled mineral constituents. Autoradiographic studies of the latter have already been reported in detail by other investigators using several radioactive elements [9, 21, 23].

The study reported herein presents data obtained from a series of autoradiographic preparations which demonstrate the formation of the components of the organic bone matrix of the young rat during rapid growth. In addition, because of its essential inseparability from and significance in the growth of long bones and because of its striking nature in $C^{14}$ autoradiograms, the formation of labeled epiphyseal-cartilage matrix is also described. Finally, it is hoped that some tentative suggestions may be submitted as to the relationship of organic-matrix formation in bone and cartilage to the acquisition and maintenance of mineral elements by these tissues.

## EXPERIMENTAL STUDY

The experimental data presented here resulted from the study of autoradiograms of several regional types of bone taken from a series of newborn albino rats, both male and female. These animals received a single subcutaneous injection of either twenty microcuries or forty microcuries of $C^{14}$ as sodium bicarbonate. The injection solution was prepared by the partial neutralization of a sample of $C^{14}$-labeled sodium carbonate in alkaline solution ** by the dropwise addition of 4 per cent acetic acid to the phenolphthalein end-point (pH 8.3). In this manner, most of the carbonate was transformed into bicarbonate.

The injections were administered within twelve hours after birth and did not exceed 0.2 cubic centimeter in volume. The animals were then sacrificed by exsanguination under chloroform anaesthesia at four, twenty-four, and seventy-two hours after injection.

The long bones were stripped of much of the surrounding soft tissues and were fixed either in Carnoy's fluid or in a 3 to 1 mixture of 95 per cent ethyl alcohol and neutralized commercial formalin.[3] Portions of the mandible and the calvarium were fixed in a like manner, thus permitting study of alveolar and membrane bone. Following dehydration in

* This investigation was begun while the author was a member of the Department of Anatomy, McGill University, Montreal, Quebec, Canada, and was supported by a grant from the Defence Research Board of Canada to Dr. C. P. Leblond.

** Obtained from the Atomic Energy Establishment of the National Research Council of Canada, Chalk River, Ontario, Canada.

dioxane, all of the tissue samples from a given animal were embedded in a single paraffin block and were sectioned at five micra.

The sections used for autoradiography were treated in the following manner. Half of the sections prepared from Carnoy-fixed blocks were treated with saliva on the slide for one hour at 37 degrees centigrade in order to remove glycogen. The remaining Carnoy-fixed sections were treated with ordinary distilled water for the same length of time at the same temperature. Successful removal of glycogen by the saliva treatment was assessed by comparison of treated and control sections stained with Best's carmine. Saliva-treated and untreated control sections were stained with hematoxylin and eosin or were left unstained prior to autoradiography.

Alcohol-formalin-fixed sections were not stained but were divided into two similar groups, embracing all of the dose levels and the time intervals. In one group, the specimens were decalcified by placing the deparaffinized sections in 5 per cent nitric acid for ten minutes or less until test sections no longer exhibited a positive von Kossa reaction, and until no evidence of the presence of bone salts could be demonstrated by the examination of the specimen in polarized light. As a further precaution, undecalcified sections were stained by means of the von Kossa technique and were also examined in polarized light in order to make certain that the small amount of bone salt normally present in such young bones had not been removed in the processes of fixation and embedding.

The sections were autoradiographed by means of the "coated method" [5, 20] in which two types of photographic emulsions were used, namely, (1) Eastman Kodak NTB3, obtained in pellicles which were soaked in a 1 per cent aqueous solution of sodium lauryl sulphate (*Dupanol*, DuPont) for twelve hours before melting and coating, and (2) NT4 emulsion, obtained in bulk, which was melted immediately for use without prior soaking.

The coated autoradiograms were stored in the dark for exposure at − 17 degrees centigrade for periods ranging from six months to one year. Following exposure, the slides were subjected to routine photographic development and fixation; they were then dehydrated in alcohol, cleared in xylol, and mounted under Canada balsam.

## RESULTS

Because the $C^{14}$ visualized autoradiographically in the bones of these animals represents only a minute fraction of the total radioactivity introduced into their bodies, very long periods of exposure of the tissue sections to the photographic emulsions were required. Others have found that up to 90 per cent of the $C^{14}$ given to rats either as carbonate or as bicarbonate ion could be recovered as expiratory carbon dioxide within twelve hours after administration [2, 15, 29]. Additional labeled material is removed during the course of manipulation for histological study. However, those reactions visualized here may safely be attributed to the presence of the radioactive isotope since similarly fixed non-radioactive tissues which were autoradiographed under identical conditions exhibited no reactions.

In view of the very short exposure of the experimental animals to the weak beta radiation of $C^{14}$ (of which only tracer doses had been used in the first place), no radiation damage to the tissues was anticipated. None was observed upon careful histological examination, nor did the quantity of bicarbonate ion introduced into the body significantly alter the amount already present as the body "bicarbonate pool". Thus, calculations indicated that the administered dose constituted less than 5 per cent of the pool [15, 17]. The effective dosage probably represented a figure considerably less than 5 per cent because of the rapidity of respiratory carbon dioxide excretion.

Therefore, it is concluded that the observations presented herein reflect metabolic phenomena occurring under normal physiological conditions.

There was no apparent difference in the pattern of $C^{14}$ uptake in bone or cartilage due to difference in dosage. The relative intensity of the autoradiographic reaction was

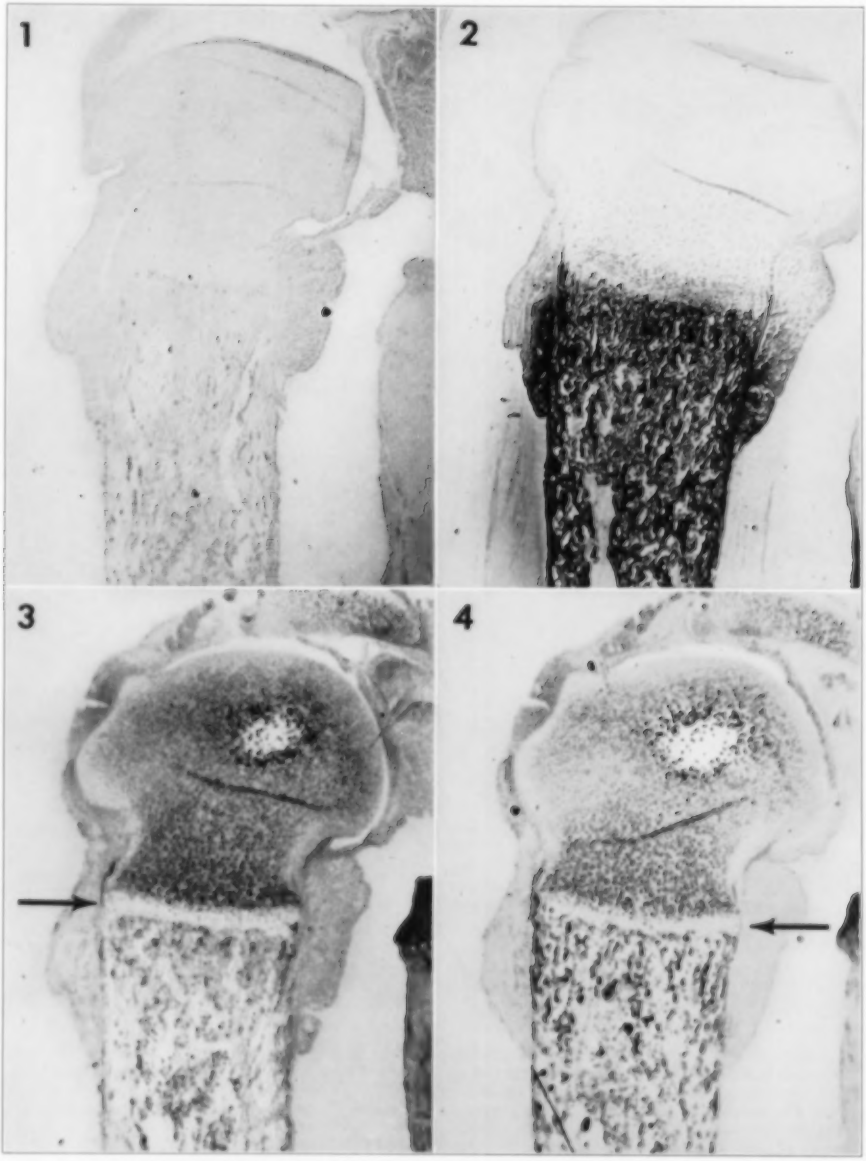



FIG. 3 FIG. 4

Fig. 1: Section of the proximal portion of the humerus from a rat sacrificed four hours after administration of $C^{14}$-labeled sodium bicarbonate. Section was decalcified on the slide with 5 per cent nitric acid and was stained with von Kossa's silver nitrate method for bone salts (× 26).

Fig. 2: Section taken from the same block as that in Fig. 1, but stained by von Kossa method without prior nitric-acid decalcification (× 26).

Fig. 3: Coated unstained autoradiogram of section taken from the same block as those in Figs. 1 and 2. Section was decalcified on the slide with 5 per cent nitric acid prior to autoradiography (× 26).

Fig. 4: Coated unstained autoradiogram of section from same block as those in Figs. 1, 2, and 3. Section autoradiographed without prior decalcification (× 26).

Although all von Kossa reactive bone salts were removed by acid treatment (compare Figs. 1 and 2), the autoradiographic images of $C^{14}$ are little affected by demineralization (compare Figs. 3 and 4). The zone of provisional calcification of cartilage is unreactive in the undemineralized section (Fig. 4, arrow), even though this region is rich in bone mineral (Fig. 2).

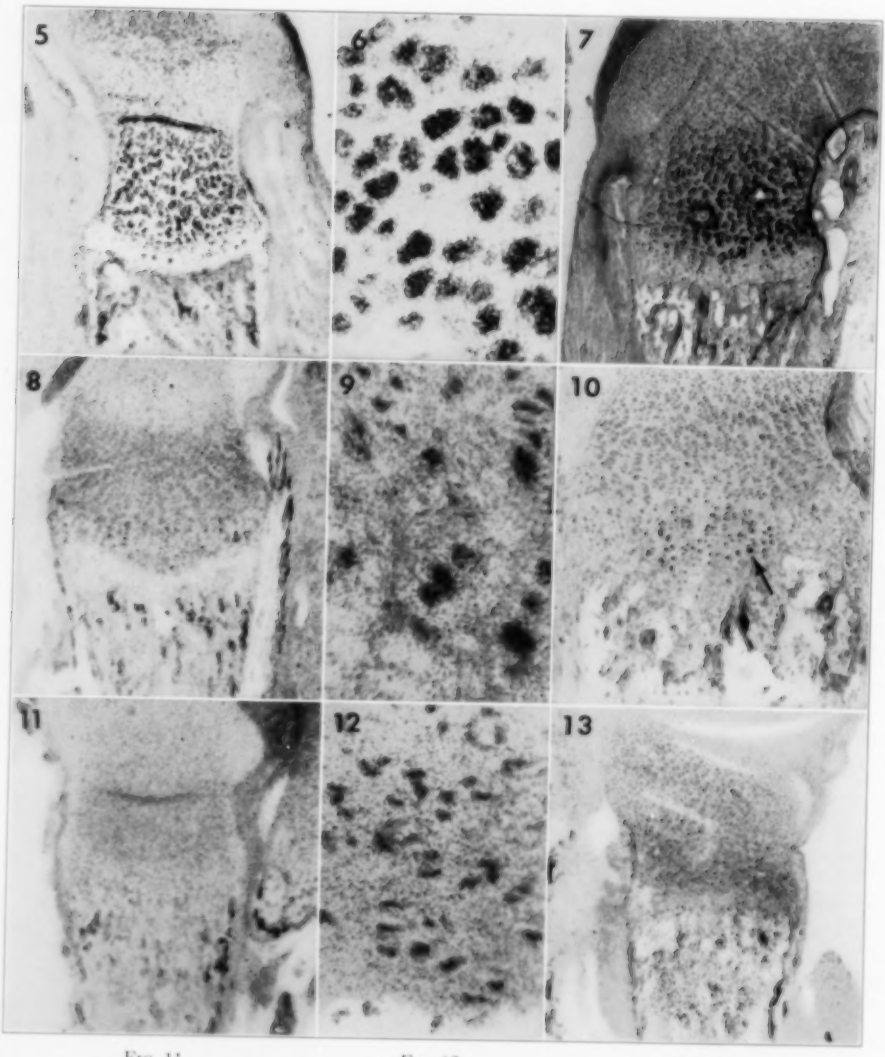



FIG. 11 FIG. 12 FIG. 13

Figs. 5, 6, and 7: Coated autoradiograms of sections of the humerus from a rat sacrificed four hours after the administration of $C^{14}$-labeled bicarbonate. (Fig. 5: Carnoy fixed, saliva treated, unstained, × 21; Fig. 6: Carnoy fixed, saliva treated, hematoxylin and eosin, × 305; Fig. 7: alcohol-formol fixation, hematoxylin-eosin, × 23.5.)

Figs. 8, 9, and 10: Coated autoradiograms of sections of the humerus from a rat sacrificed twenty-four hours after the administration of $C^{14}$-labeled bicarbonate. (Fig. 8: Carnoy fixed, saliva treated, unstained, × 21; Fig. 9: Carnoy fixed, saliva treated, hematoxylin-eosin, × 305; Fig. 10: alcohol-formol fixation, hematoxylin-eosin, × 23.5.)

Figs. 11, 12, and 13: Coated autoradiograms of sections of the humerus from a rat sacrificed seventy-two hours after the administration of $C^{14}$-labeled sodium bicarbonate. (Fig. 11: Carnoy fixed, saliva treated, unstained, × 21; Fig. 12: Carnoy fixed, saliva treated, hematoxylin-eosin, × 305; Fig. 13: alcohol-formol fixation, hematoxylin-eosin, × 23.5.)

These figures illustrate the alterations in position and intensity of $C^{14}$ autoradiographic reactions of epiphyseal cartilage and subepiphyseal bone spicules. At four hours (Figs. 5, 6, and 7), reactions of cartilage are for the most part intracellular, especially in the zone of hypertrophy (Fig. 6). The matrix is essentially unreactive except in the articular area (Fig. 5, top) where matrix adjacent to the lacunae is moderately reactive. Reactive bone spicules are seen in the subepiphyseal region across the entire face of the epiphyseal plate (see also, Figs. 3 and 18).

At twenty-four hours (Figs. 8, 9, and 10), the cartilage matrix has become moderately reactive throughout the entire cartilage (Figs. 8 and 9), while the cells have lost much of their labeled material. Only in an occasional cell (Fig. 10, arrow) do reactions of high intensity still remain. Subepiphyseal bone spicules are still quite reactive (Figs. 8 and 10; see also Fig. 19) and have been displaced downward from their initial position at four hours by growth in length of the bone.

By seventy-two hours (Figs. 11, 12, and 13), $C^{14}$ reactions in cartilage are almost entirely limited to the matrix. The black bodies shown in the cartilage in Figs. 12 and 13 are the stained chondrocyte nuclei, not autoradiographic reactions. Over the seventy-two hour period there is also a distinct generalized decrease in the over-all level of cartilage-reaction intensity (compare Figs. 5, 8, and 11). Reactive subepiphyseal bone spicules at this time are seen only at the lateral margins of the epiphysis (Fig. 11; see also Fig. 22), where they contribute to the structure of the diaphysis. The more centrally located spicules have been resorbed in the process of growth in length.

affected, that is, in comparably prepared and exposed specimens of tissues from animals receiving twenty microcuries or forty microcuries of $C^{14}$-bicarbonate, tissues from rats injected with forty microcuries gave somewhat stronger autoradiograms.

Finally, *glycogen* seemed to play little or no role in the character of the autoradiographic reactions, since both in saliva-treated-tissue autoradiograms and in untreated-tissue-control autoradiograms, the distribution and the intensity of the reactions were essentially similar.

*Effect of Decalcification* (Figs. 1 to 4)

A comparison of decalcified and undecalcified semi-serial sections of alcohol-formalin-fixed bones indicated that there was only slight alteration in the distribution and the intensity of the autoradiographic images as a result of exposure to nitric acid.

Von Kossa stained, undecalcified specimens (of the type illustrated in Figure 2) exhibited dense accumulations of metallic silver over the calcified cartilage of the epiphysis, over epiphyseal bone spicules, and over diaphyseal bone, all corresponding to the sites of bone-salt accumulation. On the other hand, in the decalcified preparations, von Kossa stained sections showed no deposits of metallic silver indicative of the presence of bone salts (Fig. 1).

Corresponding autoradiograms of undecalcified sections (Fig. 4) exhibited striking reactions over the epiphyseal cartilage, epiphyseal bone spicules, and diaphyseal bone. Degenerating cartilage, however, was unreactive, although it was obviously calcified (Fig. 4, arrow). Moreover, the distribution and intensity of these reactions in autoradiograms of the decalcified sections (Fig. 3) corresponded generally to that seen in the undecalcified sections, except that the reactions of subepiphyseal bone spicules and diaphyseal bone were somewhat less intense. The region of degenerating epiphyseal cartilage was not reactive (Fig. 3, arrow).

It thus appears that in young, rapidly growing rats, the greatest share of bicarbonate-carbon utilization in the metabolism of epiphyseal cartilage and bone occurs in synthetic processes leading to the formation of labeled organic matrix.

The amount of bicarbonate utilization in the formation of mineral elements seems to be very slight.

No incorporation of this precursor ion in the mineral element of calcified epiphyseal cartilage was observed under these experimental conditions.

With these findings in mind, the subsequent descriptions presented will deal with autoradiographically visualized $C^{14}$ occurring as a label in components of the organic matrix of epiphyseal cartilage and growing bones.

*Formation of Labeled Cartilage Matrix* (Figs. 5 to 13)

Observation of the epiphyseal cartilage of long bones at four hours revealed the presence of intense autoradiographic reactions over the regions of chondrocytes and cartilage lacunae (Figs. 5, 6, and 7). Visual comparison of the intensity of the reactions

indicated the presence of a gradient, the most intense reactions overlying the cells occupying the "zone of hypertrophy", which, for the purpose of the present discussion, is taken to include the areas of chondrocyte proliferation, palisade formation, and hypertrophy described by the earlier authors. Cellular and lacunar reactions of articular or "resting" cartilage, far removed from the epiphyseal plate, were less intense but were nonetheless quite striking (Fig. 5, top). As has been mentioned, degenerated and calcified epiphyseal cartilage immediately adjacent to the marrow cavity exhibited little or no reaction. This fact caused the latter area of cartilage to appear as a light band in the unstained autoradiograms (Figs. 3 and 4, arrows).

Except in "resting" or articular cartilage, the intensity of the reaction of the chondrocytes and the area immediately related to the lacunae far exceeded that of the remaining matrix. This is especially well demonstrated in Figure 6. However, in the articular region, the level of reactivity of the adjacent matrix seemed equal to, or in some instances greater than, that of the cells.

By twenty-four hours, the cellular and lacunar reactions of the cartilage had become less obvious (Figs. 8, 9, and 10), while the matrix of the entire cartilaginous structure had become moderately reactive. Occasionally, however, reactions of high intensity were still present over the rows of hypertrophied chondrocytes nearest the region of calcified cartilage (Fig. 9 and Fig. 10, arrow). In contrast with the latter area, reactions of articular cartilage were almost exclusively confined to the matrix at this time interval. There was also a generalized decrease in the over-all reactivity of the entire epiphyseal cartilage at twenty-four hours as compared with its intensity at four hours. The region of calcified cartilage was still essentially unreactive.

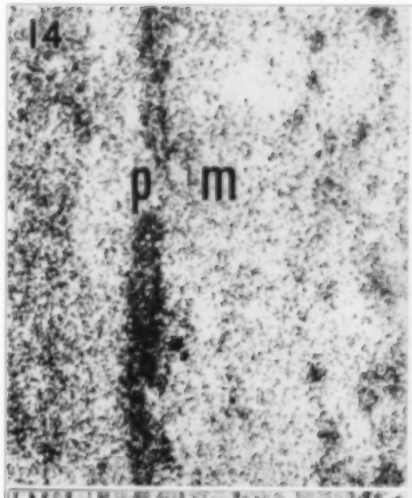
At seventy-two hours after injection, there was a further generalized decrease in the reactivity of the cartilage (compare Figs. 5, 8, and 11). The reactions of the hypertrophic zone were limited to the cartilage matrix (Fig. 12), while the regions of lacunae and cells exhibited no reaction. (Note the clear, globular areas, corresponding to the sites of the lacunae in the unstained hypertrophic cartilage seen in Figure 11.) The articular region at this time appeared to have lost matrix reactivity to a greater extent than had the rest of the epiphysis.

An additional point of interest was noted at seventy-two hours, namely, that the zone of degenerated and calcified cartilage contained labeled matrix (Figs. 11 and 13). Therefore, the non-reactive, band-like zone seen in this region at the earlier time intervals was no longer seen.

*Formation of Bone Matrix* (Figs. 14 to 22)

The most intense autoradiographic reactions in the long bones from the newborn rats at four hours after the administration of the isotope were those exhibited by the organic matrix of subepiphyseal bone spicules and by the periosteal region throughout the length of the diaphysis (Figs. 3 and 16). The latter reaction was perhaps more striking than the former. The band-like periosteal reaction lay over the most peripheral layers of diaphyseal bone and included the innermost layers of the membranous periosteum. Hence, the intervening osteoid matrix was probably also reactive (Figs. 14 and 15). The autoradiographic image over individual subepiphyseal bone spicules appeared for the most part as a peripheral coating of reactive material surrounding an unreactive cartilaginous core. In the subepiphyseal region and within the more central portions of the medullary cavity, occasional spicules which exhibited reactivity throughout their complete thickness were also seen. Finally a few spicules of the marrow cavity were seen to be entirely unreactive.

At twenty-four hours after injection, the band of reaction at the periosteal surface had increased in width centrally, so that a greater thickness of reactive diaphyseal-bone matrix was present compared with that of the earlier time interval (Fig. 19). On the other hand, the innermost matrix of the shaft remained unreactive (Figs. 17 and 18). The reac-



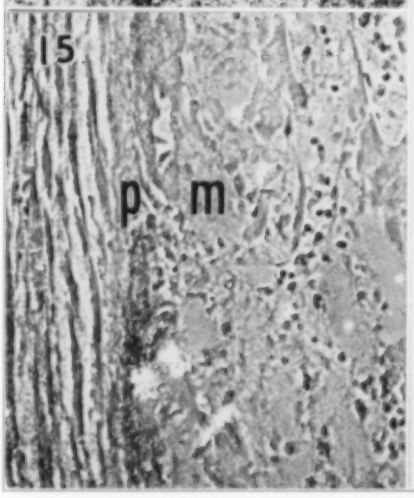



FIG. 15 FIG. 16

Figs. 14, 15, and 16: Coated unstained autoradiograms of decalcified humerus removed from a rat sacrificed four hours after the administration of $C^{14}$-labeled sodium bicarbonate. Bone was fixed in alcohol formol and was decalcified on the slide in 5 per cent nitric acid.

Figs. 14 and 15 (× 200) are respectively bright field and dark medium phase contrast microscopic views of the area indicated by the block drawn on the shaft of the humerus illustrated in Fig. 16 (× 8). The periosteum is indicated by the letter *p*, while the marrow cavity is indicated by the letter *m*. Careful comparison of Figs. 14 and 15 shows the autoradiographic reaction to lie over the periosteal region and the greatest share of the thickness of the bone trabeculae. However, the innermost portions of the trabeculae are unreactive. Reactivity is also present in some of the marrow components and in the adjacent muscle. Fig. 16 presents the over-all reaction of the humerus at this time. Note the layer of reactive subepiphyseal bone spicules at the proximal epiphysis (top). These consist of cores of unreactive cartilage with a peripheral coating of reactive bone matrix.

tion of the distal ends of the subepiphyseal bone spicules was somewhat increased over that of the four-hour interval (Fig. 19), but the roots of the spicules nearest the cartilaginous epiphyseal plate were considerably less reactive than were the tips. Medullary spicules and trabeculae presented a variable degree of reactivity. Some were quite reactive, while others were nearly unreactive. These differences could not be related to regional morphology (Figs. 17 to 19).

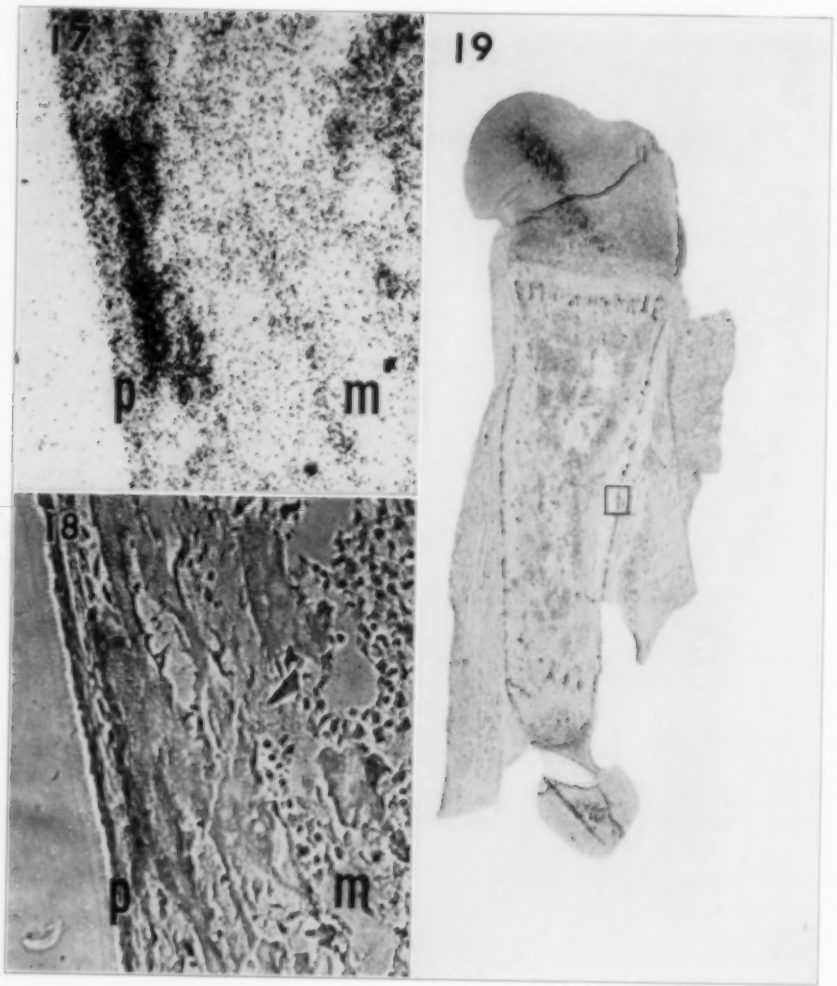
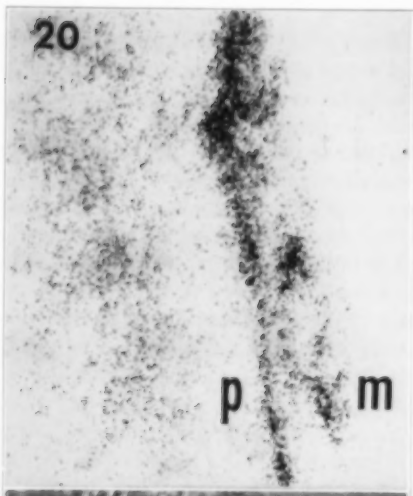


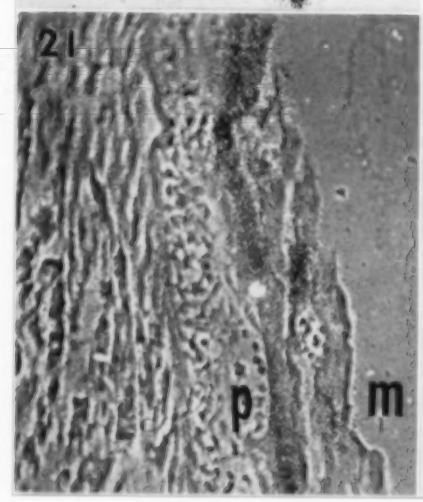

FIG. 18 FIG. 19

Figs. 17 (× 200), 18 (× 200), and 19 (× 8): Views of unstained coated autoradiograms of humerus removed from rat twenty-four hours after the administration of $C^{14}$-labeled bicarbonate (*p:* periosteum; *m:* marrow cavity).

Examination of Figs. 17 and 18 reveals that the reactivity of diaphyseal bone has to some degree been displaced centrally, so that the periosteal region is no longer as reactive as it was at four hours (Figs. 14 and 15). However, the innermost bone matrix is still relatively unreactive. Note the displacement also of subepiphyseal-bone-spicule reactions in Fig. 19 as compared with that in the earlier interval.

The reaction of subepiphyseal spicules at seventy-two hours was considerably diminished, except in those regions at some distance from the epiphyseal plate where the spicules were contributing to the thickness of the inner wall of the shaft (Fig. 22, arrow). Bone spicules immediately below the epiphyseal plate were nearly unreactive, as were the medullary trabeculae. The most marked reactions seen at this time were those of diaphyseal-bone matrix (Fig. 22). Here, the width of the reactive zone had increased centrally so as to include nearly the entire thickness of the shaft wall (Figs. 20 and 21). In some areas along the length of the diaphysis, particularly in the mid-shaft region, the most peripheral layers of matrix were not reactive.



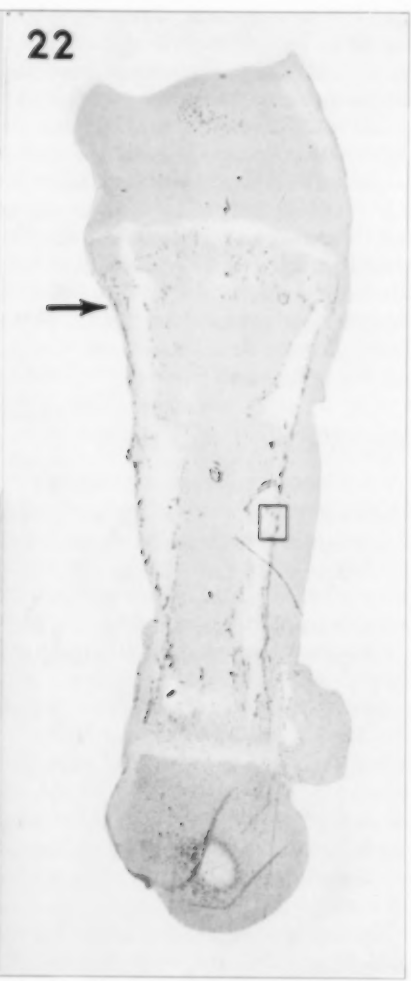




FIG. 21 FIG. 22

Figs. 20 (× 200), 21 (× 200), and 22 (× 8): Views of unstained coated autoradiograms of femur removed from a rat seventy-two hours after the administration of $C^{14}$-labeled bicarbonate. No satisfactory specimen of the humerus was available at this time interval, so the femur has been substituted. In Fig. 22 the bone has been inverted so that the rapidly growing distal epiphysis is at the top of the illustration, thus making it more comparable with the humeri shown in Figs. 16 and 19 (*p:* periosteum; *m:* marrow cavity).

Reactions of diaphyseal-bone matrix extend to the medullary surface of the shaft. In some regions, not illustrated here, the most peripheral matrix adjacent to the periosteum is unreactive. Note also that the only evidence of reaction in subepiphyseal bone spicules is seen at the lateral edge of the epiphyseal-plate region (Fig. 22, arrow), where they have become incorporated into the diaphysis.

*Formation of Matrix in Membrane and Alveolar Bone*

Although samples of calvarium and alveolar bone from the mandible were examined at all time intervals, no striking differences were observed between their uptake of $C^{14}$ and that of diaphyseal bone. Preformed trabeculae of calvarium and alveolar bone showed a peripheral coating of reactive matrix at the earliest time interval, the reaction being localized over the periosteal membranes, as well as the matrix. In a few areas, particularly of the calvarium, linear zones of reaction were visualized over regions in which no pre-

formed bone was present. These reactions were related to accumulations of connective tissue which had already showed cellular differentiation typical of membranous periosteum. In such areas, it was presumed that the reactions visualized were due to the small amounts of osteoid matrix already elaborated by this tissue and to the periosteum itself (Figs. 20 to 22).

Autoradiographic reactions of alveolar and membrane bone at the later time intervals were qualitatively similar to those already described from diaphyseal bone. Thus, at twenty-four hours, thick trabeculae of bone were observed which exhibited rather heavy coatings of reactive matrix, while thinner trabeculae were reactive throughout. By seventy-two hours, the reactions were markedly reduced in intensity, except in occasional areas. A few trabeculae still retained the appearance of being composed of a thin central core of unreactive matrix surrounded by a thicker layer of reactive matrix. Other trabeculae could still be seen to be completely reactive, although the intensity of this reaction was much reduced over that seen at the earlier time intervals.

## DISCUSSION

### *Chemical Nature of Labeled Matrix*

Considerations discussed previously [18] have led to the conclusion that the labeled soft-tissue constituents visualized autoradiographically in histological sections of the type used here are organic compounds of high molecular weight which may be characterized chemically as being either proteins or polysaccharides, or complexes of the two, that is, mucoproteins. The large quantities of citrate in bone, found associated with the mineral [24], apparently play little or no part in the reactions of decalcified bone.

*Epiphyseal cartilage*, except in its most degenerated portion, consists of a collagenous framework containing an amorphous ground substance. The ground substance contains large amounts of the metachromatic polysaccharide chondroitin sulphate, which is more or less weakly bound either to collagen [25, 26] or to other less well characterized protein components [30]. Lesser amounts of other polysaccharides may also be present, but these have not yet been completely described, nor is their significance known [14]. The region of cartilage degeneration which lies at the junction of the epiphyseal plate and the medullary cavity is further characterized by the presence of mineral material (chiefly basic calcium phosphate) embedded in its substance. The manner in which this mineral is held to cartilage is as yet unknown.

The synthesis of polysaccharides (mucoproteins) in the epiphyseal cartilage has been studied by several investigators utilizing the sulphate ion labeled with radioactive sulphur ($S^{35}$).

Dziewiatkowski [11, 12] demonstrated autoradiographically the uptake of $S^{35}$-sulphate in the epiphyseal cartilage of young rats. His observations suggested that, at early intervals, sulphur concentration was highest in the region of hypertrophic cartilage cells but that it was markedly reduced in the degenerating calcified zone. Moreover, autoradiographic images of cartilage were considerably reduced in the specimens fixed in barium hydroxide saturated formalin. He attributed this finding to the formation of a soluble barium salt of chondroitin sulphate which was released by the cartilage into the fixation medium.

More recently, Bélanger demonstrated that the uptake of radioactive sulphur in growing epiphyseal cartilage is initially intracellular [4]. At the earliest time interval examined, there was no significant uptake by the degenerating cells bordering the medullary cavity, while the hypertrophic cells immediately above the degenerative zone were intensely reactive. By forty-eight hours after injection, the reactivity of the cells and the matrix was approximately equal in intensity. At a later time, the autoradiographic reactions were present exclusively in the matrix. The intense uptake of $S^{35}$-sulphate by cartilage has been confirmed by others [7, 10].

Bélanger further demonstrated that treatment of cartilage sections with testicular hyaluronidase inhibited the sulphur reaction of the cells and the matrix more or less completely [4]. Since testicular hyaluronidase preparations are known to hydrolyze chondroitin sulphate, he concluded that the sulphur-labeled component of cartilage was chondroitin sulphate, thereby confirming the earlier suggestion of Dziewiatkowski.

While it is reasonably certain that the cartilage component mainly responsible for the $S^{35}$ autoradiograms is chondroitin sulphate, the chemical nature of the $C^{14}$-containing cartilage components is somewhat more obscure. The morphological similarity of the $C^{14}$ reactions in cartilage to those of $S^{35}$ both at early and at late intervals suggests that at least a part of the carbon is utilized in the synthesis of chondroitin sulphate. However, preliminary studies [17] of hyaluronidase-treated sections from $C^{14}$-injected animals indicate that only a small portion, if any, of the reactive material is removed. Thus, while it is possible that there may be polysaccharides other than chondroitin sulphate in cartilage which become labeled with $C^{14}$, it seems highly likely that newly synthesized collagen is the material chiefly responsible for the autoradiographic reactions observed here. This view is compatible with the earlier findings of intense and persistent autoradiographic reactions in collagenous tissues elsewhere in the rapidly growing animal, that is, tendon and fascia and the like [15].

*Bone*, in contrast with cartilage, is characterized by the presence of mineral salt (principally, a highly substituted basic calcium phosphate) embedded in, and in some way bound to, an organic substrate consisting of both collagen fibers and an amorphous intercellular ground substance. There are no known chemical differences between the collagen component of bone and cartilage. However, the ground substance of bone consists of a mixture of mucoproteins, of which chondroitin sulphate constitutes only a small portion [24]. There are additional members of this mixture whose identity is still unknown[14, 28]. It seems quite probable that bone owes to this mixture of mucoproteins its ability to acquire and to maintain its characteristic mineral component [23].

It has already been pointed out that collagen is a component common to both bone and cartilage and, indeed, it appears that the labeling of collagen with $C^{14}$ is largely responsible for the appearance of autoradiographic reactions in bone matrix. Whether the polysaccharide component of the bone matrix is also labeled with $C^{14}$ remains a moot point. Bélanger suggested [4] that the chondroitin sulphate of bone matrix becomes labeled with radioactive sulphur. Preliminary studies [17] on the hyaluronidase lability of $C^{14}$-labeled bone matrix have thus far given inconclusive results and are being repeated.

In summary, the autoradiographic reactions of bone and epiphyseal-cartilage matrix discussed herein represent primarily the labeling of newly synthesized collagen. In addition, there may be a slight labeling of newly formed chondroitin sulphate in the matrix of epiphyseal cartilage. No conclusions can be drawn regarding the role of other polysaccharides or mucoproteins of either cartilage matrix or bone matrix in the reactions observed.

*Functional Significance of Labeled Matrix*

Evidence derived from previous autoradiographic studies of *epiphyseal cartilage* with $S^{35}$-labeled sulphate [4, 11, 12], together with the present study of $C^{14}$-labeled bicarbonate, indicates that in rapidly growing rats the chondrocytes continually elaborate components of the matrix. These materials contain both protein and polysaccharide and are subsequently passed out of the cell into the cartilage matrix. Such behavior is typical not only of epiphyseal cartilage, upon which our immediate attention is focussed, but also of cartilage from other parts of the body not normally associated with osteogenesis, that is, trachea and pinna and the like [17]. While these findings fall entirely within the well established concept of the interstitial growth of cartilage, the autoradiographic reactions are so striking as to suggest further that both the rate and the extent of the formation of labeled

matrix components may be too great to be accounted for solely on the basis of the demands for growth, that is, increase in mass.

In line with the suggestion of Rittenberg, the formation of these labeled materials is assumed to be the result not only of the relatively acute demands of the tissue for new matrix during growth but also of the more chronic demands of the tissue for replacement of matrix destroyed in the processes of catabolism, that is, the requirements for tissue renewal. That the combination of these demands during rapid growth may produce a high level of metabolic activity in cartilage was convincingly demonstrated by the recent study of Boyd and Neuman, who found a level of tissue respiration in embryonic cartilage some two hundred times greater than that of adult cartilage.

On the basis of $C^{14}$ autoradiograms of the type illustrated in Figures 5 to 13, it is suggested that three zones of functional activity may be distinguished in growing epiphyseal cartilage. These are: (1) the zone of articular or "resting" cartilage; (2) the zone of hypertrophy which, as has been stated, includes the areas of proliferation, palisade formation, and true hypertrophy; and (3) the zone of degenerating and calcified cartilage.

While it will become apparent that, with the exception of the third zone, all cartilage of the body manifests essentially the same behavior with regard to $C^{14}$-labeled components of the matrix, it is convenient to describe in detail the pattern of the second zone, since it may be visualized most readily in photomicrographs. The chondrocytes of this zone seen at early intervals after injection exhibit intense autoradiographic reactions, while the surrounding cartilage matrix is essentially unreactive (Fig. 6). As has already been discussed, these intracellular reactions are attributed for the most part to the formation by the chondrocytes of labeled collagen.

By twenty-four hours after isotope administration, the cartilage cells of the second zone have lost the greatest share of their reactivity, while the matrix has become moderately reactive. This increase in, or acquisition of, matrix reactivity is predominant in the region immediately adjacent to each chondrocyte. (Note in Figure 8 the focal accumulations of photographic silver which include both the region of the cell and of the neighboring matrix but which are not so precisely localized as are those seen at the four-hour interval illustrated in Figure 5.) A few cells, particularly in the region nearest the zone of calcification, maintain intense intracellular reactivity (Fig. 9, lower center; Fig. 10, arrow).

Cartilage cells at the seventy-two hour interval are almost completely unreactive. The cartilage matrix, however, is uniformly labeled in the second zone (Figs. 11, 12, and 13).

In summary, it appears that in the second zone, embracing the areas of cartilage proliferation, palisaded cells, and cellular hypertrophy, $C^{14}$-labeled components appear initially intracellularly, having accumulated by the synthetic activity of the cartilage cells. That this synthetic activity proceeds rapidly is evidenced by the fact that, in an earlier pilot experiment, cartilage removed from a rat at one hour after $C^{14}$-bicarbonate administration exhibited reactions qualitatively similar to those seen at four hours. Following the synthesis of $C^{14}$-labeled components in the second zone, there is a progressive extrusion of this labeled matrix into the surrounding cartilage stroma, so that by seventy-two hours the matrix is uniformly labeled and the chondrocytes contain little or no $C^{14}$.

A similar, although a somewhat modified behavior, is exhibited by the cartilage cells and the matrix of the first zone, that of articular or "resting" cartilage. Here, even at very early time intervals, $C^{14}$ may be localized not only within the cells, but also in the matrix immediately adjacent to the cells (Figs. 3 and 5, top). By twenty-four hours, cellular reactions are much less obvious (Fig. 8), while the cartilage matrix is rather uniformly labeled. At seventy-two hours, no cellular reactions are observed (Fig. 11), and the intensity of the reaction of cartilage matrix has diminished to some degree. This pattern is also observed in cartilage from extra-osseous sites; it suggests a considerably more rapid synthesis and

accumulation of labeled materials than is the case in the second zone of epiphyseal cartilage. Thus, even at the earliest interval, material has already been extruded into the matrix.

The third zone, that of calcification and degeneration, departs markedly from the previously described pattern. At four and at twenty-four hours, no reactivity is seen either in the cells or the matrix. Apparently the cells of this region are so atrophic that they are unable to accumulate or to synthesize $C^{14}$-labeled products. Only at seventy-two hours after injection (Fig. 11) does this zone show any reactivity; this is restricted to the matrix as a random and homogeneous reaction. This labeled matrix probably stems from the original zone of hypertrophy seen at the earlier time intervals, which, by virtue of invasion and erosion of the pre-existing calcified zone by blood vascular and mesenchymal elements, is at seventy-two hours brought into approximation with the medullary cavity as a "new" calcified zone.

Thus, there appears to be a gradient in the rate of formation of labeled cartilage matrix, both for the purposes of tissue growth and tissue renewal. It proceeds most rapidly in the first zone (and in extra-osseous cartilage), where evidence of both the synthesis and the partial extrusion of the matrix components may be seen within four hours after isotope administration. In the second zone, however, one finds that the total time which is necessary for the elaboration and the extrusion of the $C^{14}$-labeled matrix is increased to approximately seventy-two hours. In the third zone, no such formation occurs.

From these considerations, it follows that the $C^{14}$-labeled component of epiphyseal cartilage can be considered to be physiologically older as one passes from the articular surface to the epiphyseal plate, the oldest matrix lying in the zone of calcification. If one assumes that the $C^{14}$-labeled material produced by the chondrocytes is identical throughout the cartilage, then it becomes tempting to speculate that the physiological "senility" of the cartilage matrix in the zone of degeneration is of importance in the acquisition of mineral salts by this region. Further work on this problem is in progress.

From the functional point of view, there is a striking resemblance of the autoradiographic reactions of *bone matrix* to those already described for mineral-seeking radioactive isotopes. Other investigators have shown that, at early intervals after administration to young animals, radioactive calcium and radioactive phosphorus appear autoradiographically in the areas of bone in which active growth and calcification occur [9, 32]. These reactions are particularly apparent at the periosteal surface of the diaphysis and in the region of the subepiphyseal bone spicules, but, even in these zones, the reactions are partially obscured by the simultaneous appearance of diffuse, generalized reactivity of the entire mineralized structure resulting from the processes of mineral exchange. Reactions of mineral isotopes differ from those described in the matrix, however, since the zone of calcified, degenerated epiphyseal cartilage is highly reactive following the administration of either calcium or phosphate. Because of this, subepiphyseal bone spicules, although made up of a core of calcified cartilage surrounded by a layer of bone, exhibit relatively uniform autoradiographic reactions throughout their thickness. On the other hand, at a comparatively early interval after the administration of $C^{14}$-bicarbonate, the subepiphyseal spicules display an autoradiographic reaction about their periphery, while the central cartilaginous core is not reactive. Hence it is possible to visualize the formation of $C^{14}$-labeled bone matrix in these regions quite distinct and apart from the cartilaginous elements of the structure. Moreover, diffuse exchange reactions do not occur in autoradiograms of $C^{14}$-labeled matrix, so that a greater precision in microscopic localization is possible.

The displacement of matrix reactions at various intervals following the isotope administration illustrates the rapid growth of long bones in these very young animals. Thus, in the periosteal region of the long bones, it is possible to visualize within three days a displacement of initially surface-located matrix reactions toward the endosteal face of the

diaphysis (Figs. 14 to 22). This process results from the combination of endosteal erosion of the matrix with the periosteal addition of new matrix, and the consequent increase in the width of the bone shaft. It should be noted that the labeling of matrix with $C^{14}$-bicarbonate ceases very soon after the administration of the isotope. The rapid respiratory excretion of labeled carbon dioxide causes the level of circulating $C^{14}$-bicarbonate to fall precipitously until finally, probably within twelve hours, not enough remains to permit significant labeling of the matrix. This fact, combined with endosteal-matrix resorption, gives rise to the apparent displacement of the labeled band of diaphyseal matrix from the periosteum toward the medullary cavity. Similar phenomena are observed with mineral isotopes.

Reactions of the matrix of subepiphyseal bone spicules are almost completely abolished over the three-day period of observation, except at the lateral borders of the epiphyseal plate wherein the spicules contribute to the thickness of the diaphyseal wall (Fig. 22). This observation is in approximate agreement with the findings with mineral isotopes [9, 23] and with the classical concept of the role of the epiphysis in longitudinal bone growth.

A striking feature of the autoradiographic data on $C^{14}$-labeled bone matrix appears to be that the labeled components do not play a direct role in the actual accumulation of bone salts during ossification. Thus, it is possible to visualize the labeled matrix prior to the appearance of histochemically demonstrable mineral deposits in areas of dermal-bone formation. Moreover, the region immediately adjacent to the periosteum of diaphyseal bone, corresponding to the position of "physiological osteoid", is also labeled with $C^{14}$ at early intervals after isotope administration. The chemical or structural changes, or both, which the matrix undergoes in order to acquire and to maintain bone salts during ossification seem to occur without marked alteration in the character of the $C^{14}$-labeled matrix components. A similar observation has already been made on the $C^{14}$-labeled matrix of dentine [19], which for many reasons is considered to be homologous to bone matrix. During dentinogenesis, the labeled matrix has been shown to be remarkably stable with respect to its content of $C^{14}$ before, during, and after the acquisition of dentine minerals. The nature of the changes in the matrix which make it capable of being ossified are not known at present, although in dentine a scheme involving an alteration in the character of the carbohydrate component of the ground substance was suggested [19].

It is perhaps surprising that little of the $C^{14}$ administered to young rats finds its way into the mineral component of bone as inorganic carbonate. The earliest studies of labeled carbonate or bicarbonate distribution in adult animals [1, 6, 21] indicated that the greatest share of carbon uptake by bone did, indeed, occur as mineral carbonate. While insufficient data are available at present to reconcile this discrepancy in results completely, it seems likely that the mineral compartment of young bone is naturally low in carbonate content [22], and thus little labeled mineral is formed either by new crystal synthesis or by mineral exchange following administration of $C^{14}$ to newborn animals. On the other hand, with advancing age, the carbonate content of bone progressively increases until, in the adult, carbonate constitutes a large share of the mineral and is especially available for exchange with isotopic carbonate or bicarbonate ion introduced into the body.

## SUMMARY

The distribution of a single, subcutaneous tracer dose of sodium bicarbonate labeled with $C^{14}$ has been visualized in bone and epiphyseal cartilage from a series of newborn rats by the technique of coated autoradiography.

Contrary to expectations, the deposition of radioactive carbon occurred primarily in the formation of the organic components of bone and epiphyseal cartilage, rather than in their mineral portions. Evidence is presented to indicate that the greatest share of labeled organic matrix of both bone and cartilage takes the form of newly synthesized pro-

tein, especially collagen. In cartilage, some labeling of chondroitin sulphate may also occur. Glycogen, however, plays no role in the reactions observed.

Observation of the reactions of epiphyseal cartilage over a three-day period after injection has yielded information which is interpreted as being indicative of the formation of labeled matrix by the chondrocytes. Following its elaboration, this matrix is passed from the cell into the surrounding stroma. The rate at which the chondrocytes synthesize and extrude labeled matrix varies in different regions of the epiphyseal cartilage. This variation gives some insight not only into the rapidity of the interstitial growth of cartilage, but also into the relative rapidity with which renewal of the matrix occurs. It is suggested that a reduced rate of matrix renewal in the zone of hypertrophic chondrocytes may be instrumental in causing the accrual of mineral salts in the zone of provisional calcification.

Autoradiographic reactions of the bone matrix are in general similar in position to those already described for mineral-seeking isotopes. However, because they are not obscured by diffuse, exchange-type reactions commonly encountered in mineral studies, they offer a high degree of precision for microscopic study. In some areas, it is possible to visualize the appearance of labeled bone matrix before bone-salt deposition has begun.

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# Studies of the Localization of Radioactive Gallium ($Ga^{72}$) in Bone Lesions *

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## Introduction

In previous studies with gallium and radioactive gallium ($Ga^{67}$ and $Ga^{72}$) both experimentally with animals [2,3,4] and clinically [1,6], it was shown that the metal, when administered as the citrate, is deposited in bone and has particular affinity for areas of osteoblastic activity. Earlier studies of the localization of radioactive gallium ($Ga^{72}$; half-life, fourteen hours) in patients have been reported [7,8]. A report on similar studies in which the longer-lived $Ga^{67}$ (half-life, seventy-eight hours) was used is now available [10].

In previous clinical studies of the localization of radioactive gallium in bone lesions, the method used was that of placing a small bore end-window Geiger tube, jacketed by a lead shield [8], over the suspected area, and obtaining a counting rate from the gamma-ray emission of the isotope previously administered intravenously. By the use of these earlier external counting (or scanning) methods, limitations were unavoidably placed on the accuracy and the reproducibility of the results by the inherent insensitivity of the small Geiger tubes and the small amount of $Ga^{72}$ utilized (0.3 to 0.5 millicurie). We have utilized much the same general technique as previously, but with higher doses of the isotope (two millicuries of $Ga^{72}$), heavier lead shields in order to obtain better collimation, and scintillation (crystal) counters in order to obtain greater tube efficiency. In this paper are given (1) the laboratory methods and the results of control studies for the indirect estimation of the $Ga^{72}$ content of tissues, (2) methods of scanning patients, (3) results of the study of the localization of $Ga^{72}$ in sixty-six patients with malignant lesions, and (4) results from forty-nine patients with non-malignant lesions involving bone.

## Laboratory Studies

### *Preparation and Standardization of $Ga^{72}$*

Metallic gallium of the highest purity obtainable was brought into contact with redistilled nitric acid. The acid was warmed gently for six to twelve hours, or until about 80 per cent of the original metal was dissolved. Most of the impurities remained in the residual metal. The acid solution was filtered, was evaporated to a syrupy consistency, and was cooled on ice. A crystal of $Ga(NO_3)_3$ aided crystallization, as the solution showed a marked tendency to super-cool. The first crystals were removed by filtration; these were of the highest purity obtainable.

The $Ga(NO_3)_3$ was placed in porcelain, was heated slowly to 400 degrees centigrade, and was held at this temperature for several hours. The product was $Ga_2O_3$, which was readily soluble in hot acid or alkali. Heating to 800 degrees centigrade or prolonged neutron bombardment caused an allotropic change and the oxide was no longer readily soluble in acid.

The required amount of $Ga_2O_3$ was placed in quartz, was sealed, and was irradiated for three to seven days in an atomic reactor. The Brookhaven Pile was utilized for preparation

* The opinions or conclusions contained in this report are those of the authors. They are not to be construed as necessarily reflecting the views of the Navy Department.

and a maximum specific activity of about 1.3 millicuries per milligram of gallium, three days activation, was produced:

$$_{31}\mathrm{Ga}^{71}\ (n),\ _{31}\mathrm{Ga}^{72},\ 14\text{-hour half-life.}$$

The activated $Ga_2O_3$ was dissolved in hot 20 per cent sodium hydroxide (colorless, clear solution) and was cooled. A few drops of brom-cresol purple indicator were added, and the whole solution was made strongly acid with concentrated hydrochloric acid (yellow, clear solution). Five mols of sodium citrate per mol of gallium were added, and the solution was brought to pH 6.0 to 6.5 with sodium hydroxide (red purple color). Additional water may be added in order to reduce the concentration of sodium chloride. Pyrogen-free water was used throughout to prepare all reagents, and the procedures were carried out under sterile conditions.

The $Ga^{72}$ content of the solution so prepared may be determined with a Lauritsen electroscope by comparing the gamma-ray emission of an aliquot sample with some convenient radium source, which itself has been standardized. We use three one milligram radium needles (in 0.5 millimeter platinum) with National Bureau of Standards standardization.

By calculation, one millicurie of $Ga^{72}$ will give 1.322 milliroentgens per hour at one meter. Since one milligram of radium at one meter yields 0.84 milliroentgens per hour, then

$$\frac{\text{Time Ra}}{\text{Time Ga}} \times \frac{0.84 \times (\text{mg Ra})}{1.322} = \text{mc Ga}^{72}$$

In practice, both the radium needles and the ten-milliliter $Ga^{72}$ solution sources are mounted on a wooden stand (distance of one meter) and are shielded with a one-millimeter copper shield in order to cut off beta-ray emission. The time of discharge of the electroscope is then determined.

*Counting Techniques*

Many factors must be considered when attempting to localize (or to estimate concentration in) a particular organ or structure within the body through the use of radioactive substances by external counting (scanning) methods. The principal factors are (1) the volume of tissue, (2) the differential distribution of the isotope between an area and adjacent tissues, (3) the depth of the mass, that is, the tube-to-target distance, (4) the degree of collimation obtainable by use of shields, and (5) the nature of radiation and its absorption characteristics in tissues.

In order to study the localization of $Ga^{72}$ under conditions simulating those found in the study of human beings, a series of controlled *in vitro* experiments have been completed.

If the scanning apparatus shown in Figure 1 is placed over a mass containing $Ga^{72}$, the result obtained, as counts per minute, may be considered to be the apparent $Ga^{72}$ content of the solid angle *ABCD*. Let this be concentration *A*. This count is the summation of the visible pulses of light produced in the scintillation crystal by gamma rays from many sources due to the extreme energies of the gamma-ray emissions of $Ga^{72}$ (2.0 to 2.5 mev). Therefore concentration *A* actually results from the following:

1. Direct rays from *ABCD;*
2. Scatter due to gamma rays entering *ABCD* from adjacent areas;
3. Secondary soft gamma rays due to adsorption near the upper part of the collimating tube and shield;
4. Direct and secondary rays due to the fact that 6 per cent of the initial beam passes through the ten-centimeter lead shield;
5. "Sky shine" and secondary rays produced in the metallic components above the crystal.

If all conditions are held identical, except that there is placed an additional increment of Ga $^{72}$ within the solid angle, then there is obtained an apparent concentration $B$, which in reality is a new summation of all the gamma rays which affect the crystal. This new increment of Ga $^{72}$ may be small or large in comparison with the original $A$. However, in order to simulate conditions present in patients, the conditions of $A$ are held constant and the amount and positioning of a quantity of Ga $^{72}$ (increment $X$) are varied so as to produce a series of surface counts similar to those observed in patients when scanning

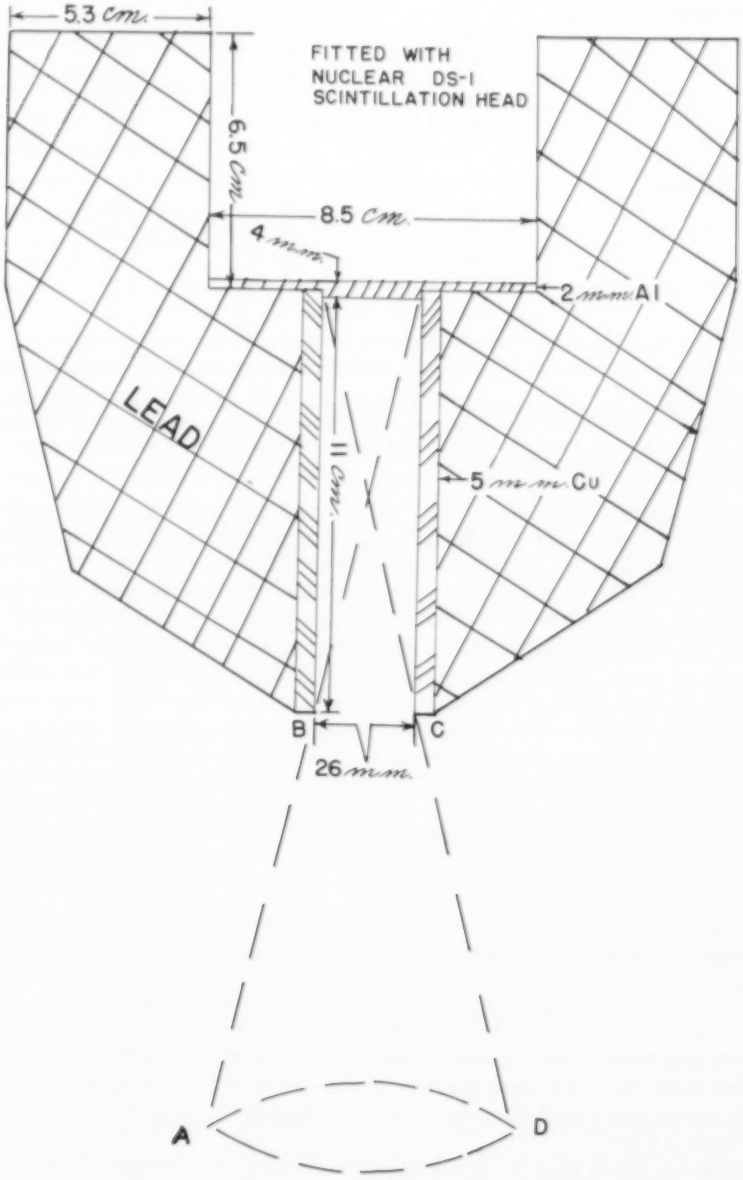


FIG. 1

TABLE I *

INFLUENCE OF CONCENTRATION GRADIENT, VOLUME OF CONTAINER, AND TUBE-TO-TARGET DISTANCE ON THE COUNTING RATE OF $Ga^{72}$

| Concentration Gradient | 100 × | 50 × | 25 × | 10 × |
|---|---|---|---|---|
| Volume of Flask | Ratio of Observed Counts | | $\frac{BBG + F}{BBG}$ | |
| A: 2.5 centimeters | | | | |
| 2 | 1.22 | 1.11 | | |
| 5 | 1.46 | 1.20 | 1.10 | |
| 10 | 2.06 | 1.40 | 1.24 | |
| 25 | 3.06 | 1.87 | 1.45 | 1.15 |
| 50 | 4.24 | 2.55 | 1.72 | 1.30 |
| 100 | | | 1.84 | 1.37 |
| B: 7.5 centimeters | | | | |
| 2 | 1.06 | 1.03 | 1.03 | |
| 5 | 1.20 | 1.12 | 1.08 | |
| 10 | 1.45 | 1.20 | 1.12 | |
| 25 | | 1.54 | 1.24 | 1.10 |
| 50 | | | 1.48 | 1.20 |
| 100 | | | 1.71 | 1.27 |

* *BBG:* Observed count at surface and over center of container (55 liters) of water, having sufficient $Ga^{72}$ to give 1,700 counts per minute.

*BBG+F:* Observed counts at same position with flask submerged below the surface (*A*) 2.5 centimeters or (*B*) 7.5 centimeters. Volume of flask (milliliters) as shown, with concentration of $Ga^{72}$ (microcuries per milliliter) within the flask, from ten to 100 times that in the fifty-five liters of water in which they were submerged, that is, the concentration gradient.

proved bone lesions. As outlined in Table I, the resultant count is a function of the volume of increment, its position, and the concentration gradient (microcuries per milliliter) between increment *X* and the water solution in *ABCD*.

A metal, open-top box similar in volume to that of a human torso (fifty-five liters) was filled with water. A plastic support was provided for the flasks, so that they could be held at 2.5 and 7.5 centimeters below the surface. Sufficient $Ga^{72}$ was mixed into the water mass so that a count of approximately 1,700 counts per minute was obtained with the nose of the lead shield at the center of the top surface of the water mass. Beneath the aperture, and on a center line, through the crystal, flasks were placed at 2.5 or 7.5 centimeters below the surface. The concentration of $Ga^{72}$ (as microcuries per milliliter) within the flasks was varied between ten and 100 times that in the fifty-five-liter water mass. The "body background" was taken to be the total observed counts at the surface (concentration *A* or *BBG*). The count observed over the center, with a flask containing added $Ga^{72}$, is taken as concentration *B* or *BBG + F*. The ratio $\frac{BBG + F}{BBG}$ will be greater than unity; and, as shown in Table I varies directly with the concentration gradient and the size of container and inversely with the tube-to-target distance.

In the light of these laboratory findings and with their application to the findings in patients with bone lesions, it appears that the concentration gradients between normal tissues (soft tissue + bone) and many bone lesions are of the order of 25 to 1 to 50 to 1.

Extending these *in vitro* studies, a second series of determinations have been made by similar methods, which show that the concentration of $Ga^{72}$ in normal adult bone to adjacent muscle tissue is of the order of 50 to 1, whereas the ratio of osteoblastic bone to normal bone is 4 to 1.

In order to verify these *in vitro* studies, which agree with certain of our earlier estimates [5,8], tissue samples were obtained at the time of surgical resection of certain bone

TABLE II

| | Relative Ga $^{72}$ Concentrations | |
|---|---|---|
| Patient with giant-cell tumor, proximal portion of tibia | | |
| Muscle | 1.0 | |
| Crest of ilium | | |
| (Normal bone to graft tumor site) | 10.1 | Ratio 2.9 |
| Bone adjacent to tumor | 29.5 | |
| Cartilage adjacent to tumor | 47.5 | |
| Soft tumor mass | 10.5 | |
| Patient with osteogenic sarcoma of the femur | | |
| $\frac{\text{Tumor Bone}}{\text{Adj. Normal Bone}} =$ | 3.6 | |
| Non-healing fracture | | |
| $\frac{\text{Adjacent Normal Bone}}{\text{Bone from non-healing fracture site}} =$ | 1.6 | |

lesions. These patients had received two millicuries of Ga $^{72}$ forty-eight hours before surgery. Gamma-ray emission in samples of tissue was counted and the concentration of Ga $^{72}$ was determined as microcuries per gram of fresh tissue.

The results from two of the three patients indicate that the ratio reactive proliferating bone to normal bone is 2.9 to 3.6 (Table II).

Autopsy findings of the relative concentration of gallium in normal and neoplastic bone, following therapeutic trials of Ga $^{72}$ are confirmed by these studies [1].

A report of the use of Ga $^{67}$ in scanning studies is now available [10]. The author does not describe the scanning apparatus nor does he give details of its operational characteristics. However, if the basic data are calculated in terms of differential uptake (lesions to normal tissue), it will be seen that the ratios vary between 1.00 and 2.8. It is probable, therefore, that his findings are similar to those given here and that the degree of localization of Ga $^{67}$ is of the same order of magnitude as Ga $^{72}$.

## CLINICAL METHODS

### *Administration of Radioactive Gallium (Ga $^{72}$)*

An infusion of 0.9 per cent sodium chloride was started into an antecubital vein just before the administration of the Ga $^{72}$ solution. When the patency of the system was assured two millicuries of Ga $^{72}$ with three to seven milligrams of gallium carrier (as citrate) was injected into the rubber tubing ahead of the infusion by means of a lead-shielded syringe. The saline infusion was then continued for two to three minutes in order to clear the Ga $^{72}$ completely from the walls of the tubing.

No untoward effects have been noted from any of the 213 Ga $^{72}$ injections thus performed at this Hospital. A few patients stated that they noted a metallic taste a few seconds after the injection. Total body radiation caused by the Ga $^{72}$ was less than two roentgens, with complete disappearance of the radioactivity within five days (70 per cent in first twenty-four hours).

### *Methods of Scanning*

The patient was stripped, placed prone on a sponge-rubber mattress, and two-centimeter circular areas were marked by some convenient method on the parts to be studied. Corresponding sites on other parts of the body were then selected, marked, and used as

TABLE III

RESULTS OF GALLIUM ($Ga^{72}$) LOCALIZATION STUDIES IN CASES OF MALIGNANT LESIONS

| | Differential [1] | No. of Cases in Group [2] | Clinical and Roentgenographic Evidence of Bone Involvement | |
|---|---|---|---|---|
| | | | *Positive* | *Negative* |
| Cases considered to be clearly negative by $Ga^{72}$ scanning methods. | 1.00–1.10 | 9 | 0 | 9 |
| Cases considered to be questionable by $Ga^{72}$ scanning methods. | 1.11–1.19 | 28 | 13 | 15 |
| Cases considered to be clearly positive by $Ga^{72}$ scanning methods. | 1.20+ | 30 | 27 | 3 [3] |

[1] The differential was determined by counting corresponding normal sites and calculating the ratio of net counts per minute as follows:

$$\frac{\text{Counts over affected part}}{\text{Counts over normal counterpart}}$$

[2] Total number of cases—sixty-seven. (Males—forty-seven, ages nineteen to seventy-seven; Females—twenty, ages twenty-eight to seventy-two). Number of $Ga^{72}$ studies—128.

[3] The three false positives in this group resulted from partial disruption of blood supply to the area through unilateral surgical procedures. (Node dissection, one seminoma, one teratocarcinoma of the testes, one breast carcinoma.)

the control. The nose of the lead collimator was placed against the skin, directly over the spot designated, and a timed count of at least 1,600 counts per minute was taken. Immediately the scintillation tube was shifted to the opposite normal site, and a similar count was made. In the study of malignant conditions and in routine scans, the following ten pairs of points were counted: mid-portion and proximal portion of the humerus, acromial process, anterior iliac crest, greater trochanter, proximal, mid, and distal portions of the femur, posterior iliac crest, and five centimeters lateral to the lumbosacral joint. In addition, twelve points along the spine from the spinous processes of the second thoracic vertebra to the fifth lumbar vertebra were studied routinely. However, in the study of solitary lesions, particularly non-malignant lesions, only the affected area and its normal counterpart were scanned.

The net counts per minute were calculated for each area, and the ratio of high count to low count was obtained. As indicated in Tables III and IV, normal areas gave ratios of 1.00 to 1.10, questionable areas 1.11 to 1.19, while in areas clearly involved, ratios ranged from 1.20 to 3.00. In general, those with active bone repair, osteoblastic malignant lesions, and normally healing fractures gave higher differentials.

Statistical analysis of the results of the counting methods indicate that individual results are accurate within ± 5 per cent. Total counts in each case always exceeded 1,600 counts per minute, with a "dark background" of 160 counts per minute or less.

Preliminary studies of several patients confirmed and extended the findings previously described [7,8] regarding the fate of $Ga^{72}$ in the organism, as determined by external scanning techniques. Selected patients, with various bone lesions, were studied at six, twenty-four, forty-eight, and seventy-two hours after the administration of the $Ga^{72}$. In those lesions which were strongly positive, differences were discernible within six hours. At twenty-four hours there were various additional areas which *appeared* to be positive. However, between twenty-four and forty-eight hours, normal tissues, including normal bone, lost gallium so that the difference between positive and questionable areas became more pronounced and the differentials in strongly positive lesions increased markedly.

TABLE IV

RESULTS OF GALLIUM (GA 72) LOCALIZATION STUDIES IN NON-MALIGNANT BONE LESIONS

| Type of Case [1] | No. of Cases | Count Differentials over Lesion [3] |
|---|---|---|
| Infections: | | |
| Tuberculosis (bone) | 3 | 1.00 to 1.28 |
| Osteomyelitis | 10 | 1.14 to 2.40 |
| Fractures: | | |
| Early studies (5 to 14 days after fracture) | 8 | 1.00 to 1.54 |
| Later studies (18 to 49 days after fracture) | 15 | 1.40 to 2.76 |
| Delayed studies (86 to 424 days after fracture) [2] | 7 | 1.32 to 2.40 |
| Others: | 5 | |

[1] Total number of cases—forty-eight. (Males, ages eighteen to sixty-four.) Number of Ga72 studies—eighty-five.

[2] Ga72 study made during healing phase.

[3]

| | Observed Differentials |
|---|---|
| Variations in normal subjects | 1.00 to 1.10 |
| Questionable Ga72 localization | 1.10 to 1.19 |
| Positive concentration of Ga72 (see Table I) | 1.20 + |

At forty-eight hours normal structures contained only 65 to 75 per cent of the gallium content present at twenty-four hours. Osteoblastic lesions on the other hand retained 95 per cent of the metal, and often showed an increased gallium content during the twenty-four to forty-eight hour period. At seventy-two hours, the radioactive decay of Ga 72 was such that statistically significant counts required too long a time for routine work.

On the basis of these results, a routine scanning schedule was established, wherein two millicuries of Ga 72 was administered to the patient and the scanning procedure was carried out but once—forty-eight hours after injection.

Evaluation of the Ga 72 content of single areas which have no normal, opposite point for comparison is difficult. In evaluating counts obtained over the spine, simple inspection of the results, and comparison of adjacent sites is the best means of determining the selective localization of Ga 72.

With the use of the spinous process of the seventh cervical vertebra as the initial reference point, the observed counts per minute normally increase rather evenly over each succeeding vertebra to the tenth or twelfth thoracic vertebra and then decrease slowly to the fifth lumbar vertebra. Marked deviation from this pattern is indicative of the localization of Ga 72 and is presumptive evidence of an osteoblastic bone lesion or of arthritic change. However, proved bone lesions produce unmistakable deviation from the normal pattern of counts in the spine, while hypertrophic arthritic lesions in older persons do not cause such marked changes. This probably results from the fact that arthritic changes usually contribute to the whole spinal pattern and thus provide little differential between adjacent sites.

*False Positive Findings*

In the study of neoplastic conditions we have found that any interruption or diminution of the blood supply to a part or member will materially reduce the concentration of Ga 72 and may cause false positive results in the normal (comparative) site. Thus in two cases of radical mastectomy with axillary-node dissection, the opposite (normal) acromial process showed a moderate degree of increased Ga 72 localization. In three cases of testicu-

TABLE V

SELECTED FRACTURES SHOWING VARIATION OF Ga $^{72}$ UPTAKE WITH TIME

| Patient | Lesions [1] | Time (*Days after Fracture*) | Ga $^{72}$ Differential |
|---|---|---|---|
| O'K. | F/S, ulna | 12 | 1.07 |
| | | 27 | 1.78 |
| | | 53 | 1.36 |
| Or., L. | F/S, femur (hip) | 14 | 1.18 |
| | | 35 | 1.09 |
| | | 78 | 1.33 |
| Ep. | F/S, tibia | 18 | 1.55 |
| | | 67 | 1.40 |
| | | 118 | 1.27 |
| Br., L. | F/S, tibia | 20 | 1.91 |
| | | 46 | 1.70 |
| | | 75 | 1.44 |
| Cl., R. | F/S, femur (shaft) | 20 | 1.16 |
| | | 39 | 1.36 |
| | | 73 | 1.29 |
| Sul. | Bone graft, femur (shaft) | 22 | 1.77 |
| | | 56 | 1.24 |
| | | 119 | 1.35 |
| Ca., J. | F/C, tibia | 35 | 2.49 |
| | | 62 | 1.92 |
| | | 133 | 1.23 |
| | | 154 | 1.23 |
| Ka., R. | F/S, tibia | 59 | 2.76 |
| | | 87 | 2.20 |
| | | 164 | 1.34 |
| Da., W. | F/C, tibia | 59 | 1.95 |
| | | 116 | 1.54 |
| | | 137 | 1.45 |

[1] F/S, Simple Fracture
F/C, Compound Fracture

lar tumor, with unilateral high abdominal-node dissection, the opposite anterior iliac crest gave moderate positive results. These five cases are included in both the second and third groups (Table III).

In two cases of carcinoma of the prostate without bony involvement of the lumbosacral spine, roentgenographic therapy (2,000 to 3,000 r) produced such a reduction in the uptake of Ga $^{72}$ in this region that the spinal pattern was markedly altered. The pattern of counts per minute indicated much less deposition of Ga $^{72}$ in the sacral spine than is found in normal subjects. This finding is interpreted to indicate that the blood supply in these osseous structures was partially destroyed by deep x-ray therapy to adjacent regions.

The rapid disappearance of Ga $^{72}$ citrate from the blood stream following intravenous administration has been demonstrated in both man and experimental animals [9]. An area of richer blood supply, particularly in osseous structures, receives and holds larger amounts of gallium. Therefore, procedures which cause a normal area to receive a considerably greater amount of blood during the first hour following administration of gallium causes this area to produce a significantly higher counting rate, and, therefore, to appear "positive" by the methods of calculation used in these scanning studies.

*Clinical Applications*

As suggested previously [7,8], it was hoped that Ga $^{72}$ scanning might be useful in the localization of various lesions involving bone before changes had occurred which were

evident on roentgenographic examination. On several occasions, we have been able to show selective Ga $^{72}$ uptake (differential $< 1.20$) in areas in which there was bone pain and no roentgenographic changes. Subsequently the progress of the disease caused such change that roentgenographic examination was positive. However, sufficient failures from the use of this procedure, including both false positives and the missing of small, but clearly positive areas, limit its usefulness with the scanning techniques herein described.

## RESULTS

### *Ga $^{72}$ Localization in Malignant Lesions*

In Table III is shown a résumé of the sixty-six cases of proved malignant lesions which have been studied by the scanning procedures outlined after the administration of a small dose (two millicuries) of radioactive gallium (Ga $^{72}$).

In the nine cases which were clearly negative by the scanning methods, all gave no clinical or roentgenographic evidence of bone involvement. In the twenty-eight cases which fell into the questionable range by Ga $^{72}$ study, it was found upon examination of the clinical records, that only fair correlation existed between the two sets of data. It is in this questionable range, when the bone lesions are small or are not readily discernible on roentgenographic study, that the Ga $^{72}$ scanning method is not a reliable index of bone involvement.

In the twenty-nine cases which were strongly positive by Ga $^{72}$ scanning, the correlation with clinical findings was excellent (26 of 29). The three false positive results occurred because of reduced blood supply to the affected areas.

As a result of this phase of the study, it is concluded that Ga $^{72}$ scanning techniques as outlined here may be useful as a means of studying the extent of a malignant lesion involving bone. However, because of the number of equivocal results obtained in the questionable range, the usefulness of the present scanning method is limited when it is utilized as a procedure for routine diagnosis.

An example of the usefulness of this technique is a case of reticulum-cell sarcoma of the right mandible (with osteogenic features), in a male, aged twenty-two, who was studied at monthly intervals for a period of three months, prior, during, and subsequent to roentgen therapy. Before and early in the course of therapy, the ratio of counts (right to left: 1.37 to 1.57) gave a strongly positive indication of selective localization of Ga $^{72}$ in the right mandible. This ratio dropped to 1.19 at the end of the roentgen therapy. At a nine-month follow-up, no significant difference between right and left mandible could be shown by means of Ga $^{72}$ scanning. It is realized that what was being followed in this case was the response of proliferating bone to x-rays and may not be an indication of the true status of the neoplastic lesion.

### *Non-Malignant Bone Lesions*

A résumé of the results from scanning non-malignant lesions involving bone is shown in Table IV.

In the three cases of tuberculous infection of bone, no definite conclusion can be drawn because of the small number of cases studied. However, the impression was obtained that there is no marked concentration of Ga $^{72}$ in tuberculous lesions; certainly, there is less than in other non-malignant lesions. In the ten cases of osteomyelitis, in those which appeared to be chronic in character, the differentials ranged from 1.14 to 1.17. In the healing stages, however, differentials of 1.30 to 2.40 were obtained, indicating marked osteoblastic activity coincidental with bone repair at the site of the healing osteomyelitis.

Study of fractures by means of Ga $^{72}$ scanning techniques is particularly useful, since the penetration of the gamma-ray emission makes possible localization of the lesion through the cast. By scanning the surface of the cast, it is possible to locate the fracture

site and to determine the relative degree of gallium localization in the lesion. Twenty-nine fractures were studied by means of this technique and the degree of Ga $^{72}$ localization was correlated with the time following injury and the healing process.

In early fractures before resolution of the callus, Ga $^{72}$ is not concentrated to a significant degree. However, as healing progresses, the differential pick-up of Ga $^{72}$ in the lesion is increased. Older lesions, which have evidence of delayed healing, show increased Ga $^{72}$ deposition during the healing phase. This is demonstrated to a greater degree in instances in which excess callus formation is present.

The five cases studied and not detailed in Table IV included two spine fusions, one herniated disc, and two bone grafts. One fusion and both bone grafts exhibited marked localization of Ga $^{72}$.

In order to correlate better the localization of Ga $^{72}$ with time, eight fractures and one bone graft were studied by means of multiple doses of Ga $^{72}$. A résumé of the results in this study is given in Table V. In general, Ga $^{72}$ localization is not marked during the early stages of fracture healing; it increases during resolution of the callus, and it decreases thereafter.

In the nine cases detailed in Table V, as well as in the study of other healed fractures (to 164 days), it was possible to locate the fracture site because of the increased activity found over the lesion by scanning. Therefore, it appears that there is residual osteoblastic activity long after a fracture has healed completely.

On the basis of these results, it appears that Ga $^{72}$ scanning techniques may be useful in the study of bone lesions, as a means of predicting the rate of healing or as a means of studying basic metabolism in healing bone lesions.

The clinical application of the technique in the determination of the viability of bone, such as the smaller fragment of the head of the femur in fractures of the femoral neck, is obvious. However, the accuracy of the method with surface scanning is not great enough for so small a fragment of bone. The use of a jacketed needle-type pick-up, thrust directly onto the bone, should overcome this problem and give accurate determinations of the blood supply of the small capital bone fragment.

## SUMMARY

1. A method has been developed for the study and localization of bone lesions through the administration of radioactive gallium (Ga $^{72}$) by external scintillation counting (scanning).

2. Laboratory studies indicate that the Ga $^{72}$ has a predilection to localize in bone, with the concentration gradient between muscle and normal bone approaching 1 to 50, while the ratio between normal bone and proliferating bone is 1 to 4.

3. A study of sixty-six patients with malignant lesions by means of Ga $^{72}$ scanning techniques indicates that this method is useful in study of specific cases but that it is of limited value in the routine diagnosis of bony metastases.

4. A study of forty-nine cases of non-malignant bone lesions indicates that in the healing phase of osteomyelitis and during callus formation and resolution in fractures, significant selective localization of Ga $^{72}$ occurs at the site of the lesion.

5. Study of twenty-nine fractures indicates that Ga $^{72}$ scanning through a cast may be useful in the study of the healing process.

NOTE: The authors wish to acknowledge with thanks the early assistance of William H. Hall, Jr., M.D., in his selection of the cases involving bony metastases. Many suggestions, as well as the records and histories of patients with malignant lesion, were made available to us by Captain R. N. Grant, Medical Corps, United States Navy, Chief of Oncology at this Hospital.

Technical assistance and scanning of patients throughout the entire study was largely through the efforts of Margaret Posipanka, HM1, United States Navy, and Robert Russell, HM1, United States Navy, of the Radioisotope Laboratory.

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# Bone Metabolism

## III. The Effect of Various Diets on the Mobilization of Strontium from the Rat Skeleton*

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### INTRODUCTION

Control over the metabolism of elements accumulating in the skeleton is a problem of major clinical importance. Early experimental investigations were directed toward the treatment of lead poisoning [3,23,29] and radium poisoning [28,41]. With the recent increase in the number of bone-seeking cationic radioactive emitters, interest has been reawakened in the subject [10,11,19,36]. The problem may be approached from several aspects: regulation of absorption into the circulation [30], minimization of skeletal accumulation after the element has entered the circulation [21], or mobilization of the element after it has been deposited in the skeleton [25,26,27]. This study deals with the latter aspect. Stable strontium was selected as the element for study because of its chemical similarity to calcium and because its metabolism probably parallels that of calcium [12,24,39]. It was felt that methods effective for the mobilization of strontium might also prove effective for other bone-seeking cations.

Several methods have been used in the past to mobilize salts from the skeleton, including the induction of active bone resorption by parathormone [1,2,14,18], by acids or their ammonium salts [17], by dietary reduction of the calcium or phosphorus intake [20], and by "dilution" techniques to accelerate the rate of "turnover" of the inorganic

* This paper is based on work performed under the United States Atomic Energy Commission Contract AT(45-1)-344.

TABLE I

ANALYSES OF DIETS

| Diet | Calcium % by Weight | Phosphorus % by Weight | Ca/P | Nitrogen % by Weight |
|---|---|---|---|---|
| Standard (I) | 0.79 | 0.42 | 1.88 | 2.96 |
| High calcium (II) | 1.84 | 0.42 | 4.38 | |
| Rachitogenic (III) | 1.19 | 0.40 | 2.98 | |
| Rachitogenic plus $NH_4Cl$ (IV) | 1.19 | 0.40 | 2.98 | |
| Low protein (V) | 0.27 | 0.39 | 0.69 | 1.0 |
| Subminimal phosphorus (VI) | 0.46 | 0.21 | 2.19 | |
| Low phosphorus (VII) | 0.45 | 0.017 | 26.5 | 3.20 |

salts [21, 25]. In a preliminary series of experiments over the past two years, several of these methods were investigated [24].

Initially, attempts were made to induce active bone resorption with dihydrotachysterol, a synthetic preparation resembling parathormone in its action. This was fed by means of stomach tube to rats for periods of up to sixty days and resulted in wide fluctuations in body weight and a high mortality rate; no perceptible acceleration of strontium mobilization occurred. These results were in contrast with the clinical findings of Hunter and Aub [23] who reported that injections of parathyroid extract in human patients with lead poisoning resulted in acceleration of the excretion of the lead.

Attempts to induce a negative calcium balance by a calcium-deficient diet resulted in some acceleration of the mobilization of strontium from the skeleton in contrast with the findings of Copp and his associates [11]. The effect of the diet was not augmented by the addition of ethylenediamine tetra-acetic acid (versene), a chelating agent which forms a strongly bound complex with calcium—this in contrast with the results recently reported by Rubin and his associates [35]. A phosphorus-deficient diet also resulted in the increased mobilization of strontium. On the other hand, attempts to accelerate mobilization by lowering the blood-calcium level, suggested by an experiment of Hastings [22], were less successful. Intraperitoneal injections of versene at relatively low dosage levels resulted in death of the rats, apparently from acute hypocalcaemia*. The rats were able to tolerate higher doses injected subcutaneously, but scars and ulcers at the sites of injection made estimation of the total amounts and the rates of absorption difficult. Mobilization was accelerated by this method, but not as rapidly as with a phosphorus-deficient diet. An attempt to increase the rate of mobilization by "dilution", by means of a high-calcium, high-vitamin-D diet, was also moderately successful.

In summary, on the basis of these preliminary studies, dietary measures affecting calcium and phosphorus metabolism appeared to offer one possible method for accelerating the mobilization of strontium from the skeleton. The following experiment was undertaken in order to compare the effects of some of these diets on body growth, histological structure of bone, chemical composition of the skeleton, and on mobilization of strontium from the skeletons of young growing rats.

* The calcium chelate has been used in the treatment of lead poisoning [13], but unfortunately calcium forms a stronger complex with versene than strontium, so the calcium versenate cannot be used in the situation under discussion.

## MATERIALS AND METHODS

One hundred and sixty-nine male Long-Evans rats were weaned at approximately twenty-one days of age and were placed on the standard laboratory diet *. They were then given daily intraperitoneal injections of strontium chloride, 0.2 milligram $Sr^{++}$ per gram of body weight, for twenty-one days. The dose was adjusted every five days. At the end of the injection period, the rats were divided into seven groups and were maintained on the respective test diets for the duration of the experiment, subgroups being sacrificed and brought to autopsy after seven, fourteen, thirty, and fifty to sixty-four days on the diets.

One group of animals, the control group, was fed the standard laboratory diet. The second group was placed on a high-calcium diet (the standard diet supplemented with 10 per cent calcium gluconate and an additional 600 U.S.P. units of vitamin D per 100 grams of diet). The third group was placed on a cereal rachitogenic diet [37,40], and the fourth group was placed on the same diet supplemented with 0.99 per cent ammonium chloride. A fifth group was placed on a low-protein diet (8 per cent). A sixth group was placed on a subminimal-phosphorus diet **, and a seventh group was placed on Kohl and Copp's low-phosphorus diet [9]. Chemical analyses of the diets are summarized in Table I.

At autopsy, the tibia was removed for histological sectioning, and the femur was removed for chemical analysis. In preparation for histological study, the tibiae were fixed in Bouin's solution, were decalcified with 10 per cent versene solution at pH 3.4, were dehydrated in alcohol and ether-alcohol, were embedded in low-viscosity nitrocellulose, were sectioned longitudinally at ten micra, and were stained with Boehmer's hematoxylin and eosin-Y.

For chemical analysis, the femora were cleaned of soft tissue, were placed in air-tight containers, were frozen as rapidly as possible, and were stored at −20 degrees centigrade. The composition was determined subsequently by weighing the femur (wet weight), drying to constant weight at 90 degrees centigrade (dry weight), and ashing at 600 degrees centigrade (ash weight). The ash weight was assumed to be equivalent to the weight of the inorganic component, and the difference between the dry and ash weights was calculated as the weight of the organic component, including fat.

Quantitative determinations of strontium were carried out with the Weichselbaum-Varney flamephotometer [44]. The ashed femur was dissolved in 0.5 milliliter concentrated nitric acid, and the resulting solution was diluted to 100 milliliters to give a strontium concentration of 0.01 to 0.10 milligram per milliliter. Phosphate ion, which depresses the emission of both strontium and calcium, was removed from solution by adsorption on finely divided metastannic acid [43]. The intensity of the light emitted by the sample was then read at 677 and 710 millimicra on the flamephotometer. Readings were also made on standard calcium and strontium solutions at the same two wave lengths. From these data, the concentration of strontium in the solution was calculated according to the equation:

$$Cs_r = \frac{\frac{b_2}{b_1} R_1 - R_2}{\frac{b_2 a_1}{b_1} - a_2}$$

* McCollum's Diet I, slightly modified as follows: ground whole wheat, 67.5%; casein (Tech.), 15%; skim-milk powder, 7.5%; vegetable fat (Crisco), 6.75%; sodium chloride (iodized), 0.75%; potassium iodide solution (450 mg. KI per liter), 1.07 c.c. per lb.; calcium carbonate, 0.5%; fish oil (vitamins A and D), 1.0%.

** Day and McCollum's Diet XVI, modified as follows: casein (Tech.), 16%; whole yellow maize, 4%; vegetable fat (Crisco), 10%; sucrose, 61.2%; cysteine in sucrose (1:19), 1%; choline: HCl in sucrose (1:9), 1%; phosphorus-free salts, 4%; carotene in Wesson Oil (3:1000), 0.3%; phosphorus-free vitamin-B complex, 2.5%; vitamin D, 380 IU/100 gr.

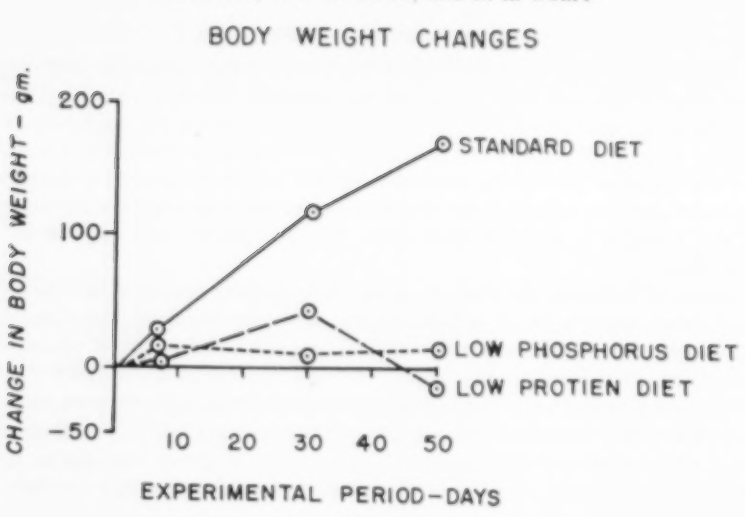



CHART I

Body-weight changes in grams plotted against experimental period in days. Rats were maintained for the duration of the experiment on the indicated diets.

where $R_1$ and $R_2$ represent the intensity readings of the sample at 677 and 710 millimicra; $a_1$ and $a_2$, the intensity readings of the strontium standard; and $b_1$ and $b_2$, the intensity readings of the calcium standard at 677 and 710 millimicra, respectively. The accuracy of the method was found to be ± 3 per cent.

## RESULTS

### *Changes in Body Weight*

For the sake of brevity, only the mean values for the changes in body weight (that is, the difference between weight at the beginning of the experiment and weight at autopsy) for each group of rats are given (Table II) and are shown plotted as a function of time (Charts I and II). The animals on the high-calcium and subminimal-phosphorus diets

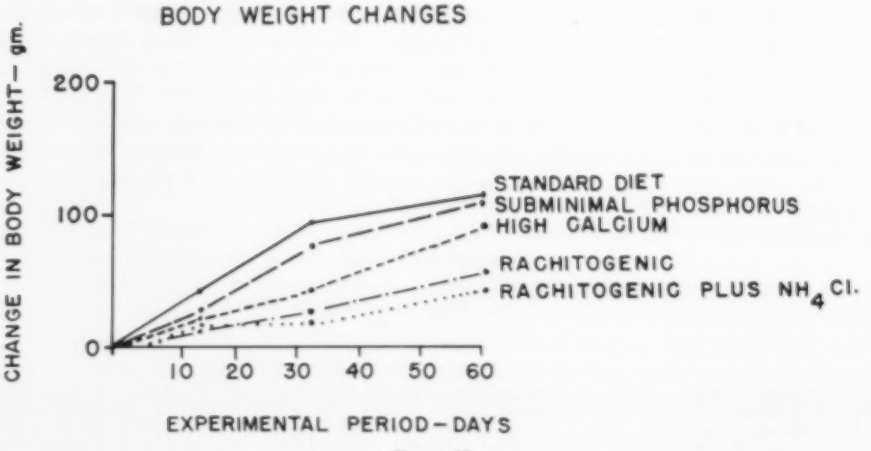



CHART II

Body-weight changes in grams plotted against experimental period in days. Rats were maintained for the duration of the experiment on the indicated diets.

showed slower gains initially than the control animals, but the final average gain in body weight for all three groups was approximately the same at the end of the sixty-four-day experimental period, ninety-six to one hundred and fifteen grams. The average gain in body weight of the rats on the Steenbock-Black rachitogenic diet and the same diet supplemented with ammonium chloride averaged between 42 and 54 per cent less than that for the rats on the control diet after sixty-four days. The weights of the animals on the low-protein diet fluctuated during the experimental period; and, at the termination of the experiments, the rats in this group showed an average loss of eleven grams in body weight. The rats on the 0.017 per cent phosphorus diet showed an average gain of eleven grams in weight during the fifty-day experimental period.

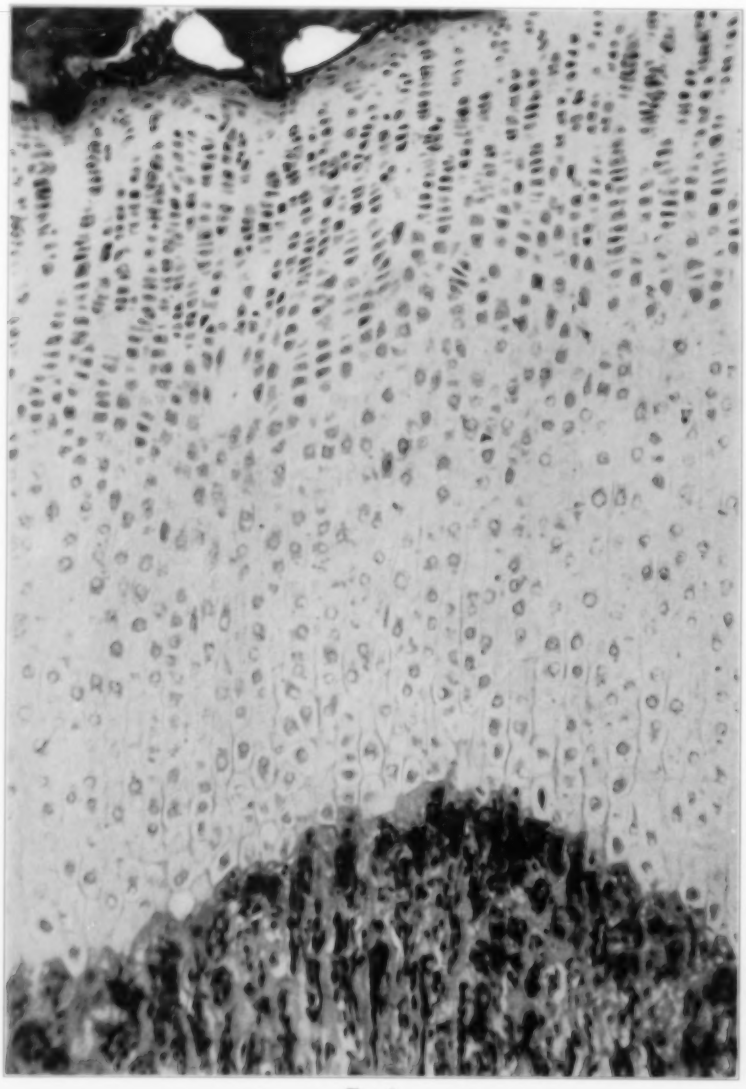


FIG. 1

Photomicrograph (× 100) of proximal tibial epiphyseal plate of 0-day control rat (age: forty-two days).

*Histological Changes*

With normal growth and maturation of the rat, there is gradual narrowing of the epiphyseal disc of the tibia, an equilibrium in width being approached between seventy-four and one hundred twenty-three days of age (the epiphyseal plate of the tibia persists until senility in the rat). There is also a reduction in the number of trabeculae. Deposition of bone around the cartilaginous anlage of the trabeculae gradually approaches the disc, until eventually a layer of bone is deposited along the "zone of erosion", sealing it off from the diaphysis[5,6,33] (Figs. 1 and 2).

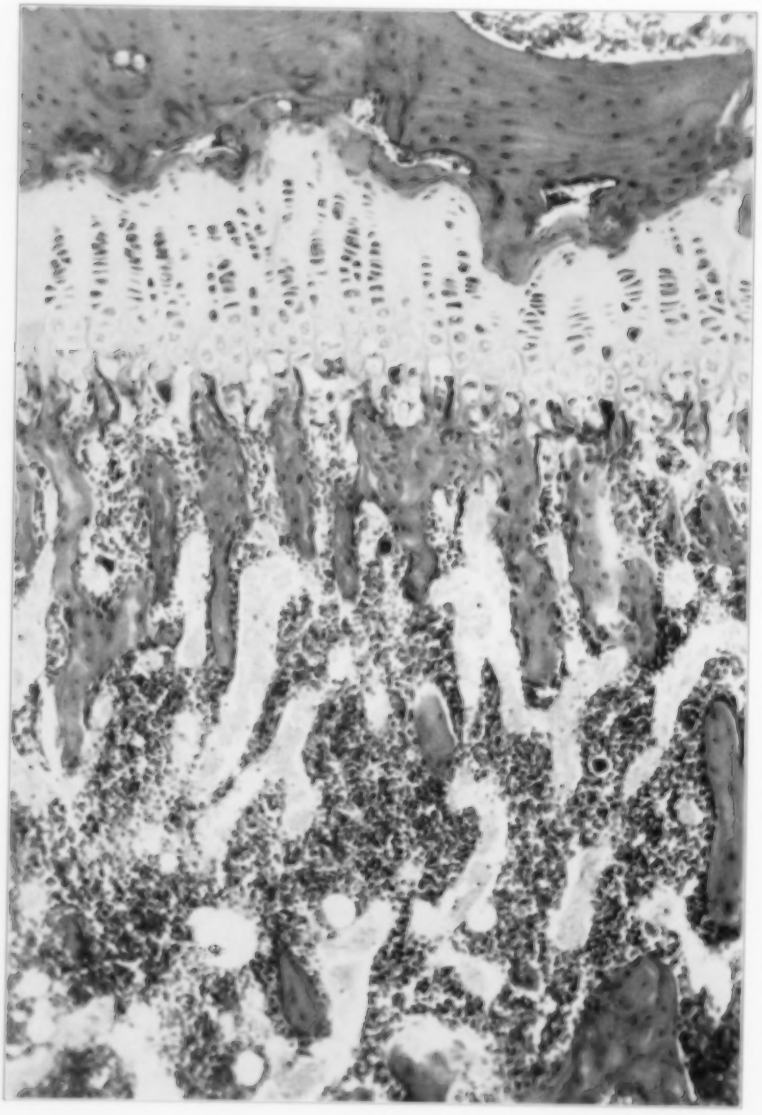


FIG. 2

Photomicrograph (× 100) of proximal tibial epiphyseal plate of 64-day control rat (age: 106 days).

The high-calcium diet had no appreciable effect on the histological structure of the bone. Steenbock and Black's rachitogenic diet resulted in widening of the epiphyseal cartilage, or rather in a delay in the normal narrowing, as well as in an increase in the width of the osteoid zones surrounding the trabeculae, changes that have been previously described by numerous authors (Fig. 3). The addition of ammonium chloride to the diet resulted in a decrease in the number of trabeculae (Fig. 4). The subminimal-phosphorus diet resulted in similar changes: the disc was wide and irregular and the trabeculae decreased in length and number (Fig. 5). The low-phosphorus diet resulted in delayed growth and narrowing of the epiphyseal disc, compared with that in rats on the sub-

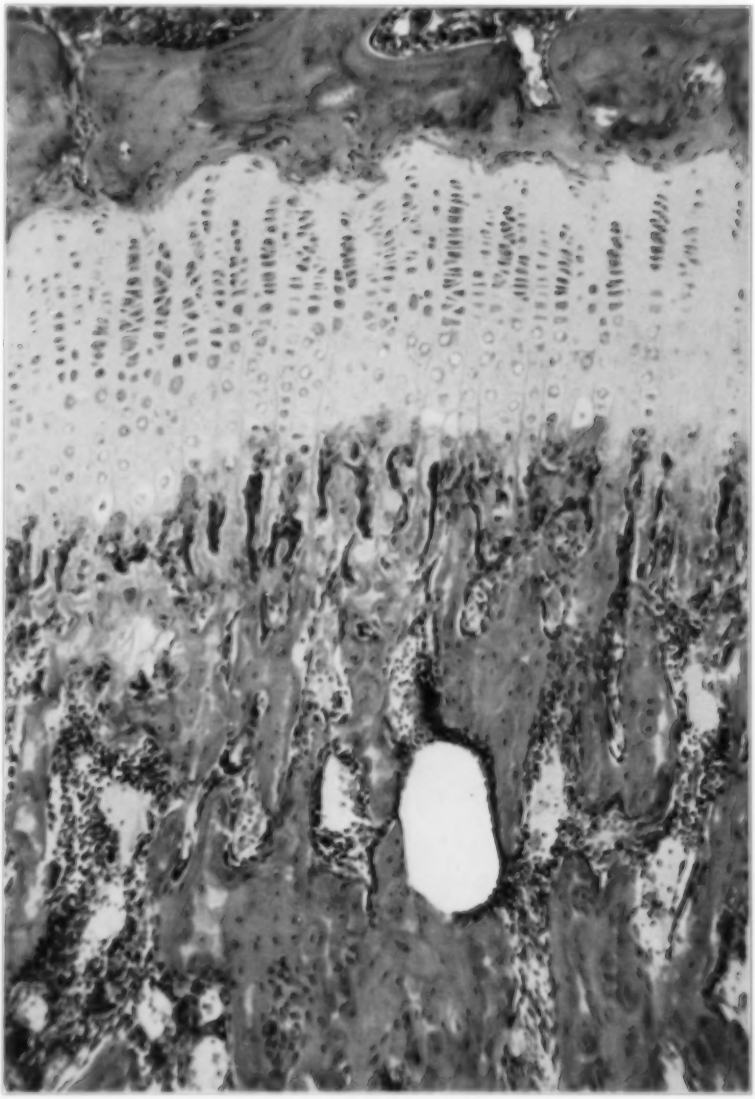


FIG. 3

Photomicrograph (× 100) of proximal tibial epiphyseal plate of rat maintained for sixty-four days on the Steenbock-Black rachitogenic diet.

minimal-phosphorus diet, so that the final width of the disc approached the normal. However, the cells of the zone of proliferation were irregular in arrangement, and the zone of vesicular cells practically absent. The trabeculae were large; they stained poorly; and there was little evidence of osteogenesis. The changes extended to the subchondral bone and to the terminal plate of the epiphysis, as well as to the cortical bone of the diaphysis (Fig. 6). The low-protein diet also resulted in narrowing of the epiphyseal plate with cessation of growth, but along the zone of erosion a plate of bone was formed similar to that found in senile animals or following hypophysectomy. There were very few

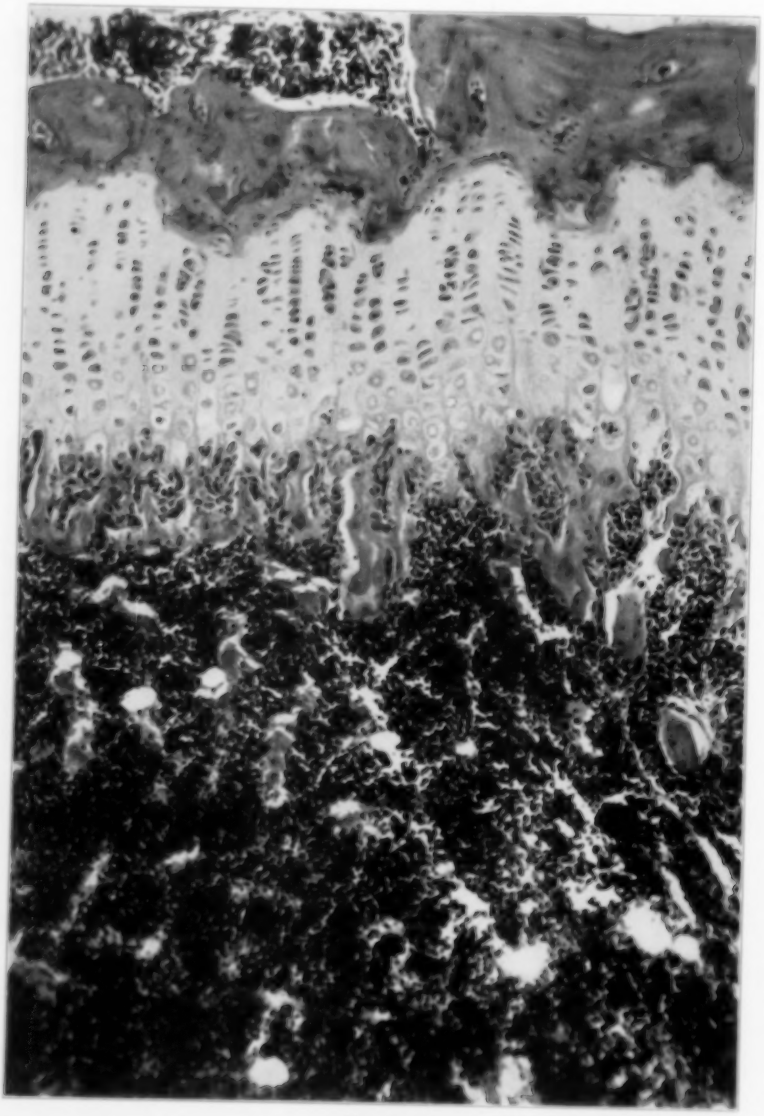


FIG. 4

Photomicrograph (× 100) of proximal tibial epiphyseal plate of rat maintained for sixty-four days on the Steenbock-Black rachitogenic diet supplemented with ammonium chloride.

trabeculae; the zones of poorly staining matrix observed in rats on the low-phosphorus diet were absent (Fig. 7).

*Changes in Chemical Composition of the Femur*

The data for the composition of the femora are summarized in Table II. Changes occurred in rats on all of the experimental diets, but the greatest variations from normal were observed in rats on the low-protein and low-phosphorus diets. The data for composition by weight and by percentage are plotted against time for these two groups (Charts III and IV).

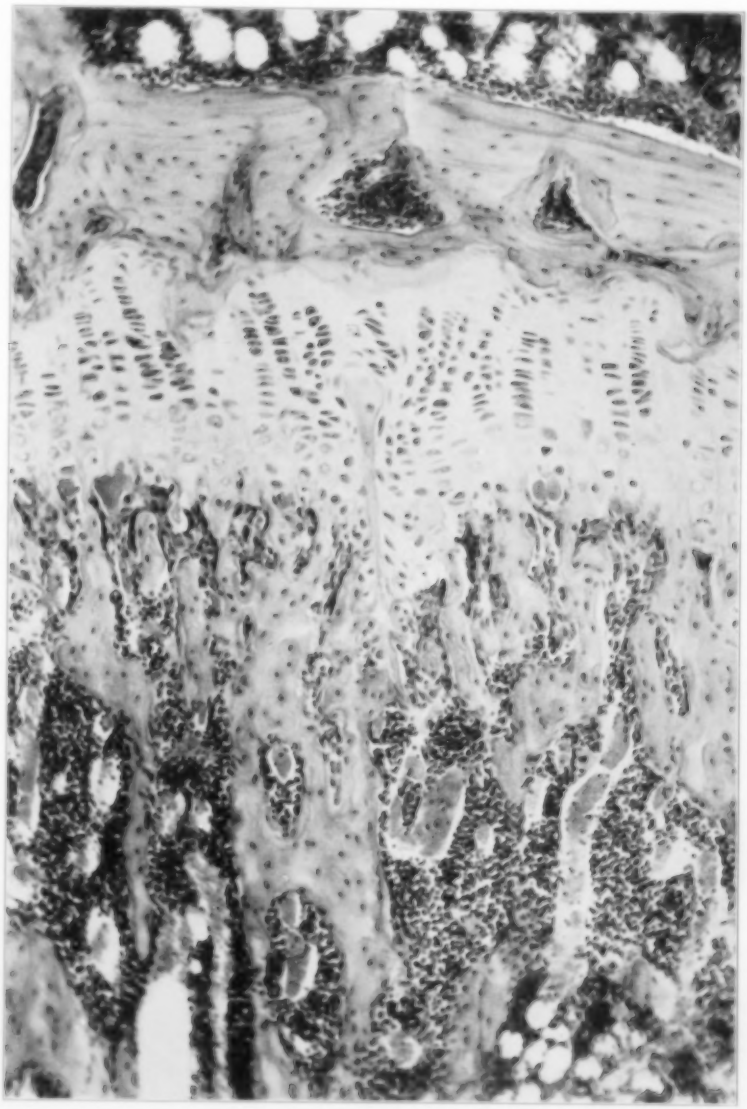


FIG. 5

Photomicrograph (× 100) of proximal tibial epiphyseal plate of rat maintained for sixty-four days on a subminimal-phosphorus diet (0.21 per cent phosphorus by weight).

With normal growth and maturation of the skeleton in the rat, there is not only an increase in the weight of the femur (Chart III), but also an increase in the percentage of ash composition of the bone, a decrease in water, and a slight increase in the organic component (Chart IV).

In rats on the low-protein diet, there was a slow increase in the weight of the femora for the first thirty days, followed by a decrease during the last twenty days (Chart III), changes that corresponded in pattern to the changes in gross body weight. However, the final composition of the bone (Chart IV) compared with a normal femur of the same wet weight (from a rat forty-two days of age as against one ninety-two days of age) showed

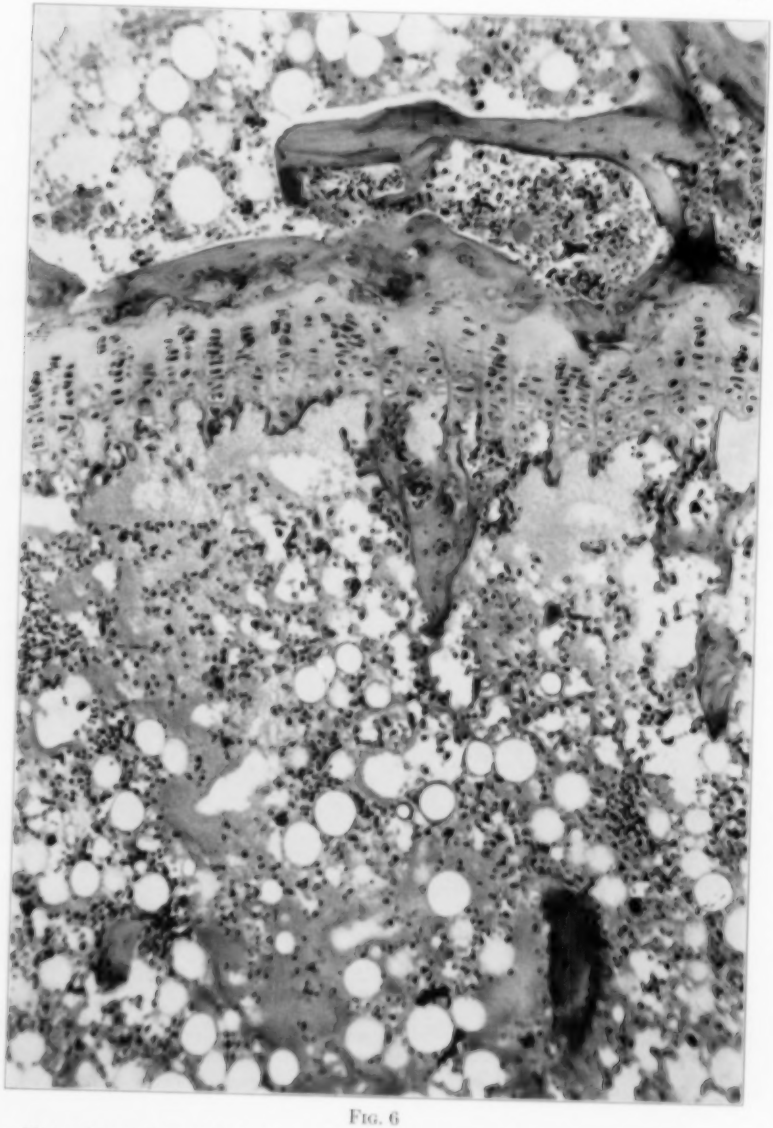


FIG. 6

Photomicrograph (× 100) of proximal tibial epiphyseal plate of rat maintained for sixty-two days on a low-phosphorus diet (0.017 per cent phosphorus by weight).

an increase in the percentage of inorganic and organic composition and a decrease in the percentage of water composition (Table III).

In rats on the low-phosphorus diet, the final wet weight of the femur was about the same as that in rats on the low-protein diet, but the final composition of the bone compared with a normal femur of the same wet weight showed a decrease in the percentage of inorganic-salt composition as well as in the percentage of water composition.

*Changes in Strontium Content of the Femur*

The mean values for the percentage of strontium found in the femur at autopsy

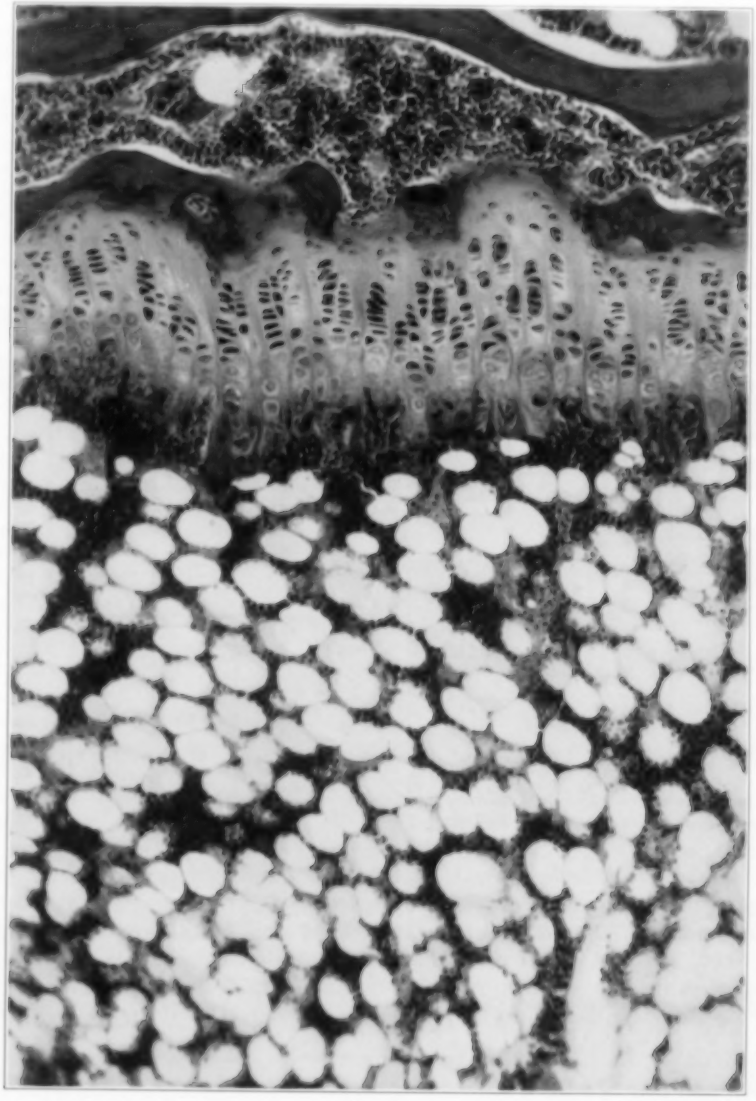


FIG. 7

Photomicrograph (× 100) of proximal tibial epiphyseal plate of rat maintained for fifty-two days on a low-protein diet (1.0 per cent nitrogen by weight).

TABLE II

SUMMARY OF RESULTS

| Group | Test Period (*Days*) | No. of Rats | Gain in Body Weight (*Grams*) | Wet Weight (*Grams*) | Analysis of Femora | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | % Water | % Organic | % Ash | % of Injected Dose in Femur* |
| Standard Diet (I) | 0 | 19 | 0 | 0.4880 | 53 | 24 | 23 | 1.59 ± 0.16 |
| | 7 | 6 | 31 | 0.6015 | 51 | 25 | 24 | 1.25 ± 0.07 |
| | 14 | 12 | 45 | 0.6379 | 46 | 25 | 30 | 1.25 ± 0.09 |
| | 30 | 6 | 118 | 0.8171 | 43 | 24 | 33 | 1.04 ± 0.08 |
| | 32 | 8 | 101 | 0.7145 | 39 | 25 | 36 | 1.21 ± 0.11 |
| | 40 | 3 | 148 | 0.6539 | 38 | 25 | 37 | 1.03 ± 0.07 |
| | 50 | 6 | 173 | 0.8728 | 36 | 26 | 37 | 1.07 ± 0.03 |
| | 64 | 10 | 115 | 0.7121 | 35 | 26 | 39 | 1.05 ± 0.09 |
| High Calcium (II) | 14 | 6 | 19 | 0.6079 | 44 | 26 | 30 | 1.18 ± 0.07 |
| | 32 | 6 | 43 | 0.6429 | 37 | 27 | 36 | 1.02 ± 0.19 |
| | 64 | 6 | 96 | 0.7126 | 34 | 28 | 38 | 0.88 ± 0.03 |
| Rachitogenic (III) | 14 | 4 | 15 | 0.4878 | 45 | 27 | 28 | 0.94 ± 0.08 |
| | 32 | 4 | 27 | 0.5641 | 43 | 27 | 30 | 0.67 ± 0.01 |
| | 64 | 4 | 62 | 0.6358 | 45 | 26 | 30 | 0.48 ± 0.01 |
| Rachitogenic plus $NH_4Cl$ (IV) | 14 | 4 | 22 | 0.5028 | 47 | 26 | 27 | 0.97 ± 0.12 |
| | 32 | 4 | 16 | 0.5293 | 46 | 26 | 28 | 0.60 ± 0.08 |
| | 64 | 5 | 48 | 0.5882 | 45 | 28 | 27 | 0.48 ± 0.03 |
| Low Protein (V) | 7 | 6 | 9 | 0.5655 | 51 | 26 | 24 | 1.35 ± 0.08 |
| | 14 | 6 | 20 | 0.5441 | 47 | 27 | 26 | 1.22 ± 0.12 |
| | 30 | 6 | 42 | 0.6264 | 42 | 29 | 29 | 1.17 ± 0.14 |
| | 50 | 6 | −11 | 0.5324 | 38 | 34 | 28 | 1.09 ± 0.11 |
| Subminimal Phosphorus (VI) | 14 | 3 | 23 | 0.5555 | 52 | 25 | 23 | 1.11 ± 0.08 |
| | 32 | 3 | 81 | 0.6961 | 47 | 26 | 28 | 0.73 ± 0.08 |
| | 40 | 3 | 57 | 0.6241 | 42 | 27 | 31 | 0.70 ± 0.02 |
| | 64 | 6 | 112 | 0.7234 | 41 | 26 | 33 | 0.57 ± 0.06 |
| Low Phosphorus (VII) | 7 | 6 | 17 | 0.5826 | 56 | 25 | 19 | 0.95 ± 0.10 |
| | 14 | 6 | 19 | 0.5151 | 56 | 25 | 20 | 0.62 ± 0.04 |
| | 30 | 6 | 8 | 0.5694 | 53 | 29 | 18 | 0.40 ± 0.03 |
| | 50 | 6 | 11 | 0.5021 | 49 | 34 | 18 | 0.23 ± 0.03 |

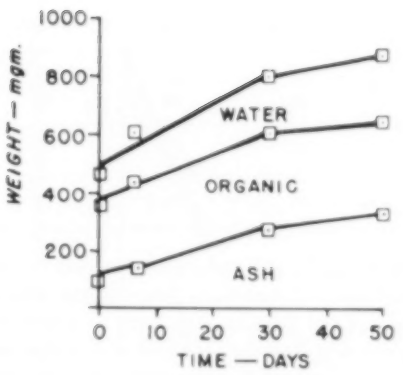
* Figures are mean and standard deviation.

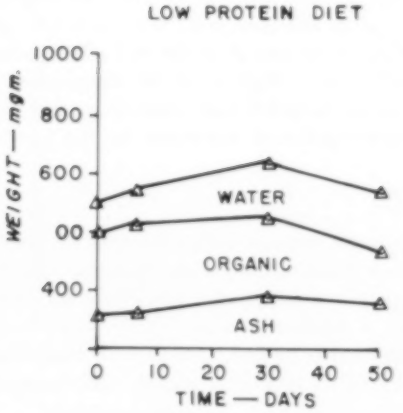
were calculated on the basis of the total dose injected plotted against time (Chart V). The femora of the rats sacrificed one day following the termination of the strontium injections contained an average of 5.4 milligrams of strontium, 1.6 per cent of the total dose injected. The control rats maintained subsequently on the standard diet showed a slow decline in the percentage of injected strontium retained in the femora, and at the end of sixty-four days the femora contained approximately 3.3 milligrams, or 1.1 per cent

Chart III: Change in weight of water, total organic and inorganic portions of femora of rats maintained on indicated diets. Each point represents an average of data from four to six animals.

Chart IV: Change in percentage composition of femora of rats maintained on indicated diets. Each point represents an average of data from four to six animals.

CHANGES IN COMPOSITION OF FEMUR



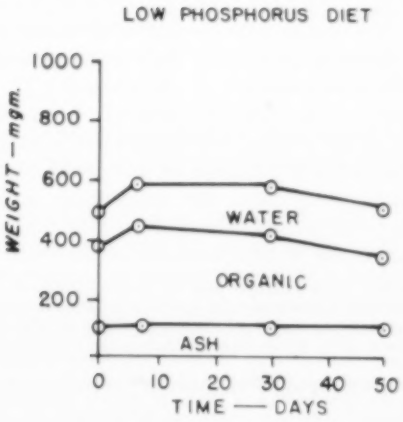
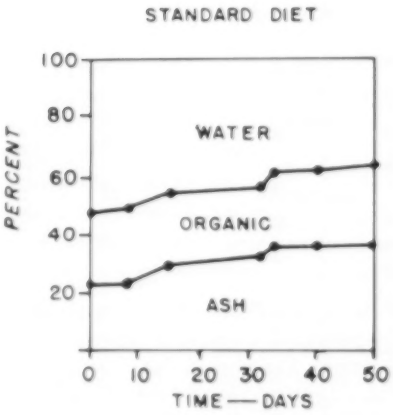
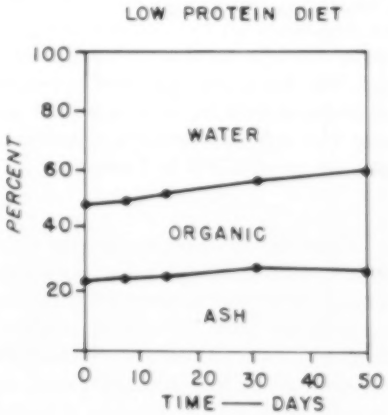




Chart III

CHANGES IN PERCENTAGE COMPOSITION OF FEMUR



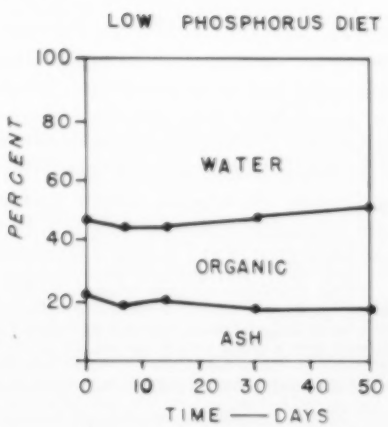




Chart IV

TABLE III

COMPARISON OF COMPOSITION OF FEMUR BY CHRONOLOGICAL AGE AND BY WET WEIGHT

| Diet | Chronological Age (*Days*) | Wet Weight of Femur (*Grams*) | Composition of Femur | | |
|---|---|---|---|---|---|
| | | | % Water | % Organic | % Ash |
| Standard | 42 | 0.49 | 53 | 24 | 23 |
| | 92 | 0.87 | 36 | 26 | 37 |
| Low protein | 92 | 0.53 | 38 | 34 | 28 |
| Low phosphorus | 92 | 0.50 | 49 | 34 | 18 |

of the injected dose. The amounts of strontium found in the femora of the rats on the low-protein diet were only slightly less than the amounts of strontium found in the femora of rats on the control diet (1.0 per cent of the injected dose at fifty days as compared with 1.1 per cent for the controls). The high-calcium diet increased the rate of mobilization slightly; and at the end of the experiment, 0.88 per cent of the injected dose remained in the femur. The subminimal-phosphorus diet, the rachitogenic diet, and the rachitogenic diet supplemented by ammonium chloride were more effective, 0.57, 0.49, and 0.47 per cent of the injected doses, respectively, remaining in the femur at the end of sixty-four days. The low-phosphorus diet apparently was the most effective of the diets tested in mobilizing strontium, with only 0.24 per cent of the injected dose remaining after fifty days. The results, expressed in terms of the mobilization of strontium by the various diets, are summarized in Table IV.

## DISCUSSION

Theoretically, there are several ways in which an element within the skeletal matrix might be mobilized: (a) during the normal process of remodeling of the skeleton *, (b) by exchange with ions in the interstitial fluids [32] (this surface process would not involve a change in the total amount of inorganic salt or of organic matrix), (c) by selective demineralization of the skeleton, leaving the organic matrix behind, as in *in vitro* decalcification, and (d) by active resorption of the entire matrix including organic and inorganic components **.

Of the diets used, the low-protein diet had the least effect on accelerating strontium mobilization from the skeleton, although it did profoundly alter the histological appearance of the skeleton and the general health of the rats. (After fifty days on the diet the experiment had to be terminated because of the poor condition of the animals.) There was no evidence that selective demineralization of the skeleton occurred, but it did appear that the diet induced over-all resorption of the matrix. A slow increase in weight of the femur during the first thirty days on the diet was followed by a decrease to approximately the original weight during the last twenty days, the composition of the bone remaining relatively constant during the latter period (Chart IV). This suggests that resorption of the recently deposited surface layers of bone occurred as the result of

* This possibility perhaps deserves further explanation. It is assumed that in some portions of the actively growing skeleton, for example, regions of metaphyseal cancellous bone, an element once deposited could be mobilized during remodeling. Following mobilization into the circulating body fluids, it is further assumed that a small percentage would be excreted (about 20% of the amount mobilized), and that the remainder would be redeposited in newly forming matrix [4].

** The mechanism of strontium mobilization may be dependent on the actual position of this element in the crystal lattice, and work is currently in progress under the direction of Dr. L. H. Jensen, Department of Anatomy, University of Washington School of Medicine, to compare the x-ray diffraction pattern of normal bone with that of bone containing strontium.

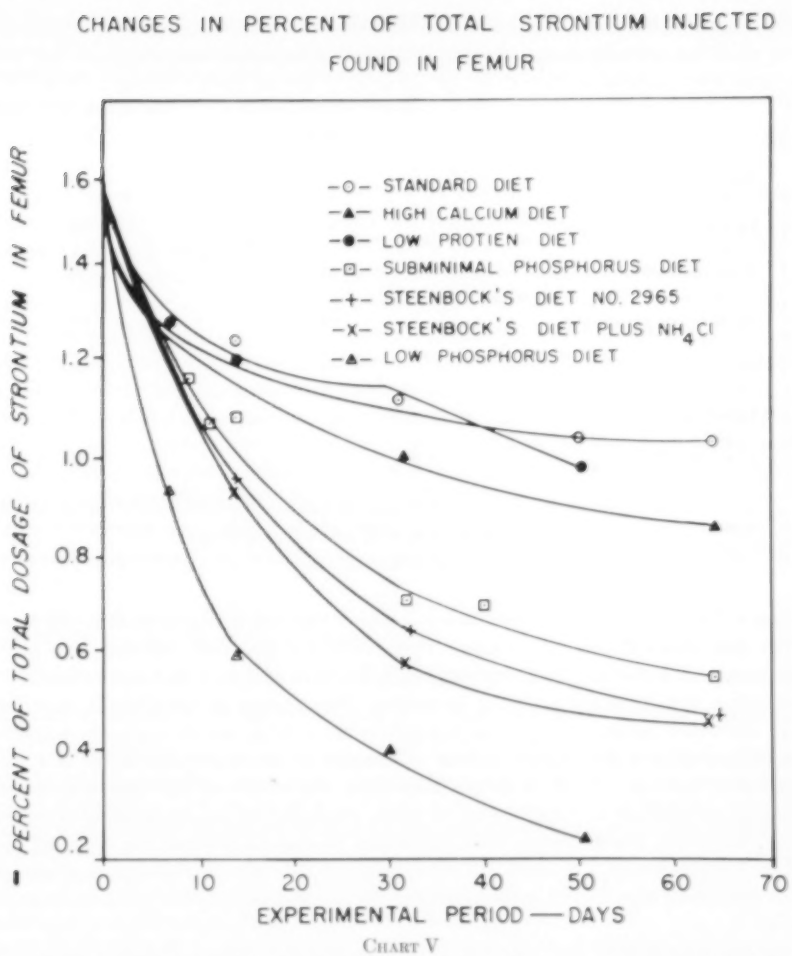



CHART V

Change in percentage of total strontium injected found in femora of rats maintained on various diets. Each point represents an average of data from four to six animals, except for the standard diet where each point represents six to twenty animals. Percentage of total strontium in femur was calculated as:

$$\frac{\text{mgms. Sr found in femur}}{\text{total mgms. Sr injected}} \times 100$$

protein starvation. Such a view would be consistent with the histological picture, as well as with the slight acceleration of strontium removal during the latter period (Chart V).

The high-calcium diet, next in order of effectiveness, probably acted by "diluting" strontium mobilized by ion exchange or in normal remodeling of the skeleton. The question arises as to whether the relative amounts of calcium and phosphorus in the diet are more important than the absolute amounts. This has been studied by several authors, including Bethke and his associates and Brown and his associates; the evidence presently available suggests that the ratio of calcium to phosphorus in the diet becomes important when the absolute amount of phosphorus is reduced to 0.1 to 0.3 per cent. The high-calcium diet had little effect on the over-all chemical composition or on the histological appearance of the skeleton, and it probably did not significantly alter absorption from

TABLE IV

PERCENTAGE OF STRONTIUM MOBILIZED FROM RAT FEMUR*

| Diet | Experimental Period (*Days*) | Strontium Mobilized* (*Per cent*) |
|---|---|---|
| Standard (I) | 64 | 31 |
| Low protein (8 per cent) (V) | 50 | 37 |
| High calcium (II) | 64 | 45 |
| Subminimal phosphorus (VI) | 64 | 64 |
| Rachitogenic (III) | 64 | 69 |
| Rachitogenic plus $NH_4Cl$ (IV) | 64 | 70 |
| Low phosphorus (VII) | 50 | 85 |

* $\%\ \text{Sr mobilized} = \%\ \frac{\%\ \text{of injected dose at onset} - \%\ \text{injected dose at end}}{\%\ \text{of injected dose at onset}}$

the intestinal tract, since the phosphorus content of the diet was greater than 0.3 per cent.

The Steenbock-Black rachitogenic diet, with 1.2 per cent calcium, 0.4 per cent phosphorus, and a calcium to phosphorus (Ca/P) ratio of 3 to 1 was more effective than the foregoing diet in mobilization of strontium. Phosphorus in cereal-grain rachitogenic diets is combined in part as inositol hexaphosphoric acid, which is poorly available [16]. The Steenbock-Black diet is also lacking in vitamin D, an important factor in intestinal absorption of calcium. Thus, it is probable that the effect of the diet was to reduce the amount of calcium or phosphorus, or both, available for calcification of the growing skeleton. However, the deficiency was not severe enough to produce the classical picture of rickets histologically. The addition of ammonium chloride enhanced to a slight extent the effectiveness of the diet in mobilizing strontium, probably by inducing acidosis in the animals.

The low-phosphorus diet was the most effective diet tested. Optimal dietary phosphorus requirements for normal growth and skeletal metabolism of the rat are between 0.56 and 0.69 per cent [7], and apparently these animals are extremely sensitive to phosphorus deficiency [15,24,42]. A reduction of the phosphorus content of the diet to 0.2 per cent resulted in definite acceleration of strontium mobilization, and the Kohl-Copp low-phosphorus diet with 0.017 per cent phosphorus was even more effective in this respect. It should be noted, however, that the health of the rats was jeopardized by the latter diet, and the experiment had to be terminated early. The phosphorus-deficient diet seemed to cause selective demineralization of the skeleton—the weight of the femur increased during the first seven days on the diet, but the ash weight decreased and continued to decrease during the ensuing experimental period. However, the final effect may have been the result of combined bone destruction and replacement by uncalcified osteoid tissue and cartilage. The histological appearance of the tibia would seem to support the latter possibility.

There are several ways in which a phosphorus deficiency could alter the inorganic-salt metabolism of the skeleton:

1. It might affect the metabolism of the bone cells directly, and it probably affects deposition of the calcium hydroxyapitite crystals in the organic matrix;

2. It could affect the soft-tissue metabolism and body-fluid homeostasis with secondary mobilization of phosphate from the skeletal reserves to provide for body needs—a teleological argument that leaves something to be desired (about 13 per cent of the phosphorus of the adult human body is present in the soft tissues [35]);

3. The lack of phosphate may have a direct effect on kidney function, the deficiency increasing the renal "clearance rate" for calcium and strontium [12,42].

The effect of a phosphorus-deficient diet on the metabolism of strontium following irradiation, and the mathematical analysis of strontium metabolism [36] will be the subjects of the next papers in this series.

## SUMMARY AND CONCLUSIONS

A study has been carried out to determine the effect of various diets on body growth, histological structure of bone, and chemical composition and mobilization of strontium from the skeletons of young growing rats. Animals having from 5 to 6 per cent of the mineral portion of their skeletons as strontium were maintained on (a) a standard laboratory diet, (b) a low-protein diet (8 per cent), (c) a high-calcium and high-vitamin-D diet, (d) a subminimal-phosphorus diet, (e) a cereal rachitogenic diet, (f) a cereal rachitogenic diet containing ammonium chloride, and (g) a low-phosphorus diet.

The low-phosphorus diet had the most profound effect on strontium mobilization and skeletal mineralization, while the standard diet and the low-protein diet had the least effect.

NOTE: The authors would like to express their sincere appreciation to Mr. Duane F. LaViolette for his technical assistance in carrying out these experiments.

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# The Localization of Chloride in Hyaline Cartilage by Histochemical Technique

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For a number of years, the position of chloride in skeletal muscle has been investigated, and it is now generally agreed that the chloride is situated in the extracellular compartment. Little or none of the chloride is found inside the muscle fibers under normal metabolic conditions. The experimental evidence for this accepted position of chloride in skeletal muscle comes from the following studies:

1. The observations of Hastings and Eichelberger (1937) who found that only by assuming the extracellular position of chloride could their results on the acid-base balance of tissues be correlated;

2. The sulphate perfusion experiments of Amberson, Nash, Mulder, and Binns (1938) who showed that chloride could be removed without affecting the cellular phase;

3. The direct microscopic studies of Gersh (1938) who found no chloride inside the muscle fibers;

4. The experiments of Manery and Haege (1941) who used radioactive chloride and concluded that the chloride was outside the cells;

5. The experiments of Barlow and Manery (1954) who showed that the "chemical" cell volume of chick muscle, based on the chloride concentration of muscle being entirely extracellular, was the same as the "morphological" cell volume, based on planimeter measurements of projected histological sections.

In the recent studies of Eichelberger and her associates [5, 6, 7], the assumption was made that "under normal metabolic conditions the chondrocytes of cartilage contain no chloride". The purpose of this investigation is to clarify the position of chloride in hyaline cartilage by use of descriptive qualitative microscopic methods rather than chemical analyses. The method used is the silver nitrate stain as described by Gersh [8] in which the chloride of a section is precipitated as silver chloride. By radiation with an arc lamp, the silver chloride precipitate is converted to silver oxide which is seen as yellow-brown granules.

## EXPERIMENTAL PROCEDURES

All sections for study were made from the cartilage of the femoral condyles and ribs of twelve- to sixteen-week-old puppies. Six puppies were whelped and were raised in an isolated puppy room. They were given a supplemental diet of canned dog food and milk until weaned at eight weeks. During the rest of their life span the puppies received a balanced diet and appeared normal. For removal of the cartilage specimens, the puppies were anaesthetized with intravenous nembutal. The joint was exposed and pieces of articular cartilage one by one by two millimeters were removed and were dropped immediately into isopentane chilled to a viscous state (−150 degrees to −160 degrees centigrade) by liquid nitrogen. The costal cartilage was treated similarly. The tissues were removed after five to ten minutes from the isopentane and were placed quickly into a stainless-steel wire-screen "boat". The "boat" was nineteen centimeters long, three and one-half centimeters wide, and was divided into nine compartments. The boat was placed into a Benditt and French [3] freeze-drying apparatus. The tissues were desiccated over phosphorus pentoxide for five to seven days at a pressure of $10^{-6}$ millimeters of mercury at −32 degrees centigrade.

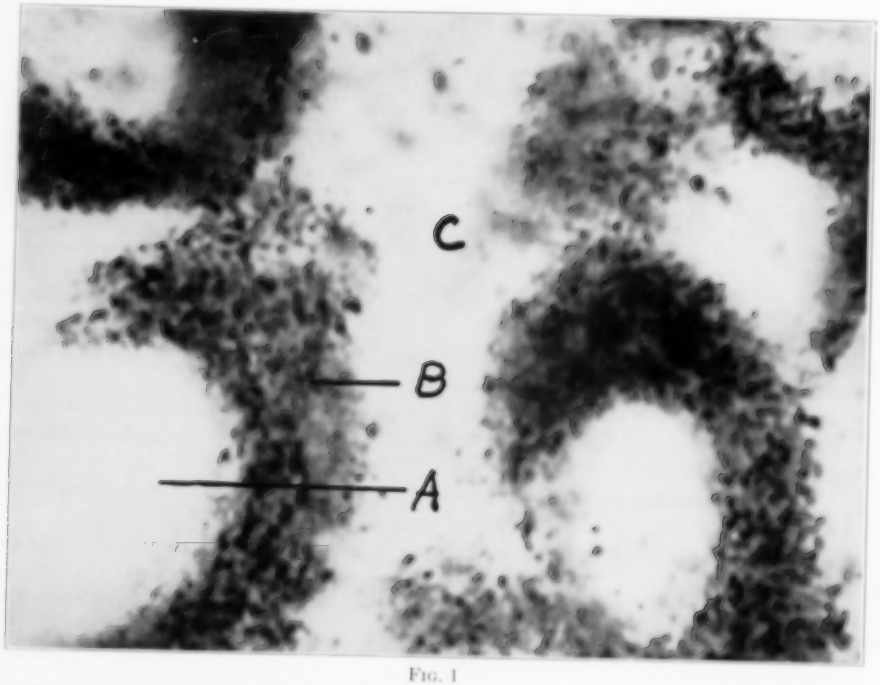


FIG. 1

Figs. 1, 2, and 3: Photomicrographs of a section of femoral articular cartilage. The section was stained to show the distribution of chloride which appears as minute yellow granules (black granules in the photomicrograph). The granules representing chloride are limited to the matrix. The cells are free of granules. Identifying letters: *A*, cells; *B*, granules representing chloride; and *C*, matrix.

Fig. 1. Photomicrograph (× 3,500) of cartilage near the articular cortex shows a large chloride collar in the pericellular area. The granules spread out over a considerable area of the remainder of the matrix.

The tissues were embedded in the following manner. Histowax paraffin (melting point, 58 degrees centigrade) was heated to 100 degrees centigrade for twenty minutes in a vacuum tube; it was cooled to 65 degrees centigrade. A tissue was removed from the freeze-drying apparatus and was dropped quickly into an aluminum-foil cup, eight centimeters long, containing some of the air-free dehydrated wax at 65 degrees centigrade. The cup was made by forming heavy aluminum foil over the end of a centrifuge tube. The foil cup with the tissue was returned to the vacuum tube for forty minutes. The cup filled with paraffin containing the specimen was then removed from the tube and the paraffin was allowed to harden. After twenty-four hours the cup was placed in a refrigerator for two to three days. The aluminum-foil cup was then torn off the paraffin and the block was shaped for cutting.

Sections from one by one to one by two millimeters were cut at six micra on a Spencer rotatory microtome and were mounted dry near the corner of a small cover slip. Fixation to the cover slip was accomplished by heating slightly and pressing the section with the finger tip. The section was placed in a small container just large enough to accommodate the cover slip (small plastic coasters) and containing ten milliliters of petroleum ether (boiling point, 40 to 60 degrees centigrade) freshly distilled over metallic sodium. The container was then tightly covered. After ten minutes the cover slip and section were removed; the excess petroleum ether was removed by passing the cover slip quickly through a small flame. The section was cooled and was covered with one drop of staining solution. The section must be small enough to be covered instantly with one drop so as to reduce the diffusion factor to a minimum.

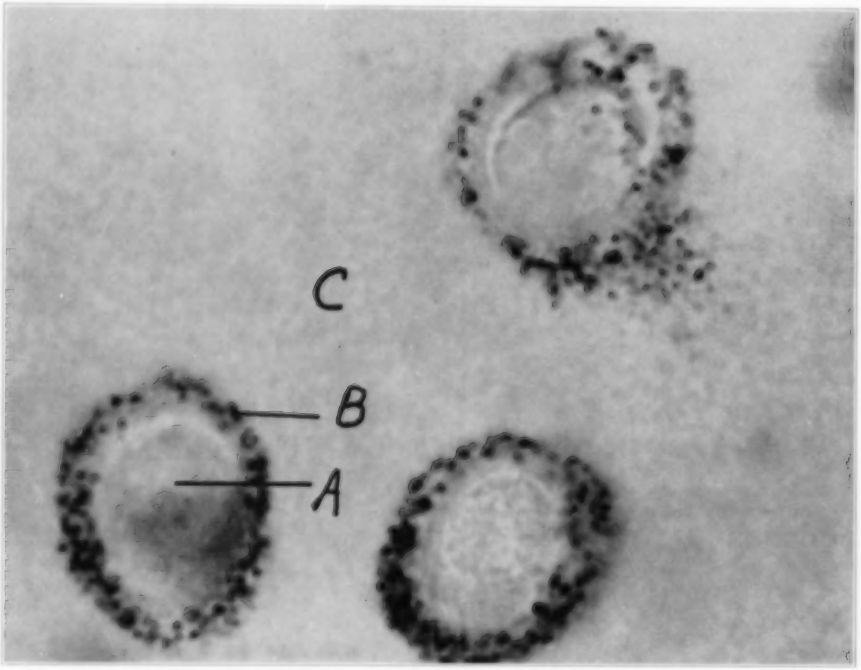


FIG. 2

Photomicrograph (× 3,500) of articular cartilage midway between the articular cortex and joint surface. The pericellular granules are less dense and the collar is not as broad as those seen in Fig. 1. The rest of the matrix contains practically no granules.

The drop of staining solution was left on the section for one to two minutes and then drained off. One drop of glycerol was placed over the section and the cover slip was mounted on a slide. The section was radiated by a carbon arc light (Cenco Optical Disk Illuminator) long enough to convert the precipitated silver chloride to silver oxide which is seen as a yellow-brown granule. The length of time of radiated ion necessary was determined by frequent microscopic examinations.

The granules are best visualized by a light source emitting parallel rays. A 1.25-millimeter condenser and an apochromatic oil immersion lens of approximately the same aperture were used to decrease refraction. If no granules were seen on the upper or lower surfaces of the section and if those present were distributed evenly throughout the depth of the section no diffusion had occurred.

### PREPARATION OF STAINING SOLUTIONS

*Solution I for staining chloride:* Sixty grams of silver nitrate were made to 100-milliliter volume with water. To saturate the solution with silver chloride, drops of a 5 per cent sodium chloride solution were added until a considerable precipitate of silver chloride was attained. This solution was then saturated with silver phosphate by adding drops of a 5 per cent solution of sodium phosphate until a yellow precipitate of silver phosphate appeared. Fifteen to twenty milliliters of phosphoric acid (specific gravity, 1.7) must be added to the 100 milliliters of silver nitrate solution in order to prevent the precipitation of silver carbonate and phosphate. After the mixture was filtered through No. 42 Whatman filter paper into a brown bottle, it was ready for use. Immediately before staining with this solution, two to three drops of water were added to approximately ten milliliters.

*Solution II for staining chlorides, phosphates, and carbonates:* Sixty grams of silver

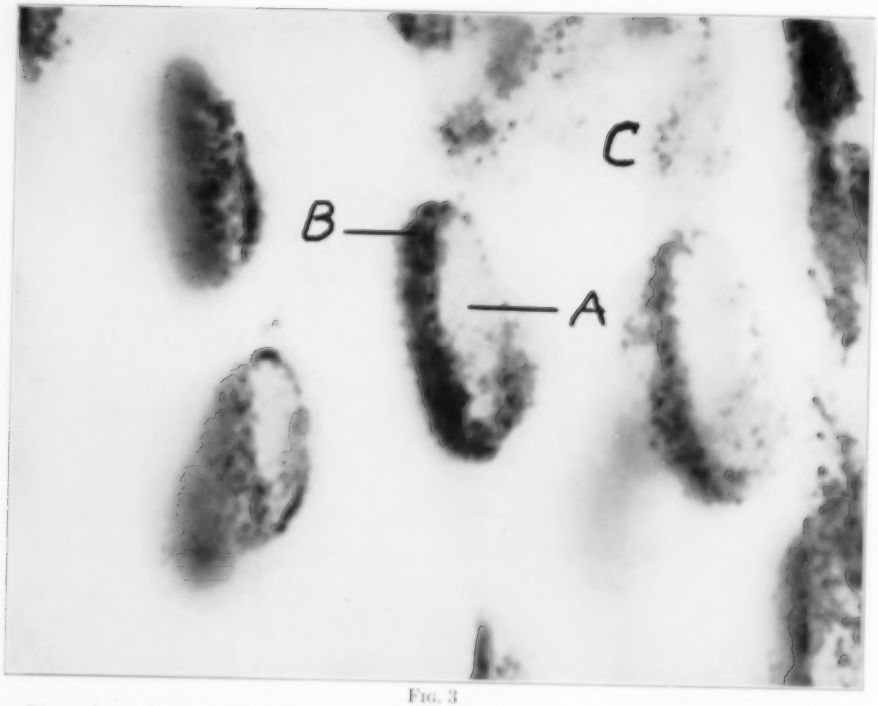


FIG. 3

Photomicrograph (× 3,500) of femoral articular cartilage near the joint. The cells are elongated and free of granules. The granules overlying the cells are in superimposed matrix. In the matrix of this region there are few granules.

nitrate were made to 100-milliliter volume with water. Drops of a 5 per cent sodium phosphate solution were added until a yellow precipitate of silver phosphate appeared. After the yellow precipitate settled, drops of a 5 per cent sodium chloride solution were added until considerable white precipitate formed. This mixture was filtered into a brown bottle which was stored in a dark place at room temperature. To the portion used for staining two to three drops of water to every ten milliliters were added.

## RESULTS

The most striking feature seen in a section stained with solution I was the dense collection of granules in the extracellular matrix immediately adjacent to the chondrocyte forming a collar-like or halo arrangement. No granules were to be seen within the cells. The extracellular matrix farther away from the cells contained only occasional granules.

The sections stained with solution II were yellow-brown in color and the granules were fairly evenly distributed throughout the matrix with only a slight accentuation of concentration of color and granules around the cell. The chondrocytes were stained dark brown. This distribution of granules was due to precipitated silver chlorides, phosphates, and carbonates—the latter two ions exist throughout the matrix, as well as within the cell.

Cross sections of the cartilage removed from the femoral condyles revealed the cells adjacent to the articular cortex to be large and surrounded by a "collar" of granules. The diameter of the granular area was four to five times that of the cells. Even the interstitial substance away from the chloride collar had an appreciable amount of scattered granules (Fig. 1). About midway between the articular cortex and the joint surface, the chondrocytes were small and few in number. The granules surrounding these cells

were less dense and described a circle no greater than twice the diameter of the cell. Very few granules were seen in the remainder of the matrix of this area (Fig. 2). At the joint surface the chondrocytes were flattened and elongated and were surrounded by a narrow collar of granules. Practically no granules were seen in the matrix.

It has been established that the chloride content of the extracellular phase is increased around young cells.[2] It seems evident, therefore, that the cells close to the articular cortex of the femur are young cells and those near the joint represent much older cells.

Sections of the costal cartilage stained with solution I revealed the same pericellular collection of silver oxide granules. The heaviest staining occurred subperichondrially. Therefore, as evidenced by the heavier staining, the justaperichondrial cells are probably younger than those cells near the center of the rib cartilage.

## DISCUSSION

Because of the distribution of the silver oxide granules produced by the staining solution I it was suspected that another anion, possibly chondroitin sulphate, was combining with silver rather than with chloride. In order to eliminate the chloride from the reaction several sections were washed with water, stained with solution I, and radiated with the arc lamp two to three times longer than usual. No staining occurred. These washed sections, however, showed no decrease in metachromasia when stained with toluidine blue, although metachromasia is no longer accepted as an absolute indication of the presence of chondroitin sulphate. Blix and Snellman have shown that only minor amounts of chondroitin sulphate can be extracted by cold water; consequently washing the section with water removed all of the chloride and practically none of the chondroitin sulphate. This strengthens the identification of the silver oxide granules as being converted from silver chloride.

NOTE: The author wishes to express his appreciation to Dr. Isidore Gersh and Dr. Lillian Eichelberger for their constructive criticism during this work.

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# Skeletal Cryptococcosis (Torulosis)

## Report of a Case and Review of the Literature

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In human beings, the most common form of cryptococcosis is chronic meningoencephalitis with fatal termination. Infection of the skeletal system by this fungus is a rare pathological entity and in a review of the literature, the authors found reports of only twenty-four cases.

Jesse reported what he thought was the first case of skeletal cryptococcosis in 1947. In 1950, however, Collins reviewed over 200 cases of cryptococcosis and found sixteen additional cases of skeletal involvement. To these cases he added three of his own. In that same year Fisher also reported two new cases of skeletal involvement; these cases and two more very recently reported [12, 13] bring the total number of recorded cases of skeletal cryptococcosis to twenty-four.

A critical analysis of the original reports of the cases reviewed by Collins shows that in four cases only the skull was infected and that in three of these four cases the involvement was secondary to primary disease of the brain and meninges. In one case, that of Cleland, the organism had been originally reported as *Blastomyces dermatiditis*, but because the description of the organism was more compatible with that of *Cryptococcus neoformans*, the case was included in Collins' series. In two instances, no cultures were obtained, and the disease was not reproduced in laboratory animals. The diagnosis of skeletal involvement was therefore unconfirmed, although the presence of generalized cryptococcosis was proved. If all of these doubtful cases, including the cases exhibiting secondary skull involvement, are excluded, only eighteen cases of confirmed, primary skeletal disease due to *Cryptococcus neoformans* have been recorded. To this series the authors will add a new case report.

### CASE REPORT

A colored boy, ten years of age, was seen in the Out-Patient Department of the John Gaston Hospital on January 2, 1954. This boy had fallen from his bicycle two weeks previously and had injured the left knee. An immediate examination had shown no apparent serious damage to the bone and soft tissue of the knee, and the injury had received no further attention from the parents until approximately three days before admission. At that time the knee had become swollen and was increasingly painful, and there had appeared associated local hyperaemia and a moderate systemic response with malaise and fever. The past history of the boy was negative, and the family history was non-contributory. A review of the systems disclosed no additional complaints.

The physical examination made on admission revealed an acutely ill child with a rectal temperature of 102.6 degrees Fahrenheit, a pulse of 110 per minute, and a respiratory rate of twenty-four per minute. The child weighed sixty-five and one-half pounds; his head, neck, heart, lungs, abdomen, and external genitalia all were essentially normal. Examination of the left knee revealed considerable local elevation of temperature, considerable swelling, and acute local tenderness. It also revealed a marked distention of the joint suggestive of effusion. Active motion of the joint was limited to between 170 and 160 degrees, and the circumference of the knee was twelve and five-eighths inches as compared with eleven inches for the circumference of the normal right knee. There was no muscle atrophy in the left thigh.

Significant laboratory studies on admission revealed a white blood count of 16,150 per cubic millimeter; 80 per cent of the cells were polymorphonuclear leukocytes; 19 per cent, lymphocytes; and 1 per cent, monocytes. No eosinophiles were seen. The hematocrit was 38 per cent.

FIG. 1

FIG. 2

Fig. 1: A roentgenogram of the left knee. There is no evidence of bone involvement.

Fig. 2: A roentgenogram made thirty days after the onset of illness but prior to the institution of therapy. A destructive lesion is apparent in the medial end of the clavicle.

Fig. 3: A roentgenogram made at the same time as the roentgenogram in Fig. 1. An early lytic lesion is apparent in the upper end of the right radius.

FIG. 3

A roentgenographic examination showed distention of the left knee joint and a pneumonic consolidation in the right lower lung field. No other abnormalities were noted.

Approximately fifty cubic centimeters of thick, greenish-yellow purulent material was aspirated from the left knee; and 500,000 units of penicillin, 0.5 gram of streptomycin, and 125,000 units of hyaluronidase were injected locally. Every day thereafter the joint was aspirated and was irrigated copiously with saline; and penicillin and streptomycin were injected locally; hyaluronidase was injected every other day. (Cultures had been obtained on admission, but no organisms had been isolated.) For approximately two weeks, thirty to fifty cubic centimeters of purulent material was obtained from the knee daily; after that time, however, the effusion was less rapid, and aspiration and local injections of antibiotics were performed only as needed. On February 1, 1954, the patient began to complain of pain in the right elbow, and a swelling of the right sternoclavicular joint was noted.

A roentgenographic examination was made on January 29, 1954. Complete resolution of the pneumonic consolidation at the right lung base was apparent, and there was no evidence of bone destruction in the left knee (Fig. 1). In the examination of the right sternoclavicular joint and elbow, however, expansion of the medial end of the clavicle with bone destruction was seen and the presence of an early osteolytic lesion in the right radial neck was demonstrated (Figs. 2 and 3). The patient continued to exhibit daily temperature elevations that were as high as 102 degrees Fahrenheit.

Further laboratory studies were performed. The purified protein derivative skin tests (No. 1 and No. 2), the routine agglutination tests, the repeated blood cultures, and the stool and urine cultures all gave negative results. No essential change in the hematological picture was found.

On February 13, 1954, a biopsy of the right clavicle was performed. A large centrally-expanding destructive lesion was found in the medial end of the clavicle. This lesion contained a friable, greyish-yellow material. It was thoroughly curetted, and the wound was closed primarily. The tissue removed was sent to the laboratory for bacteriological and histopathological study, with the following results:

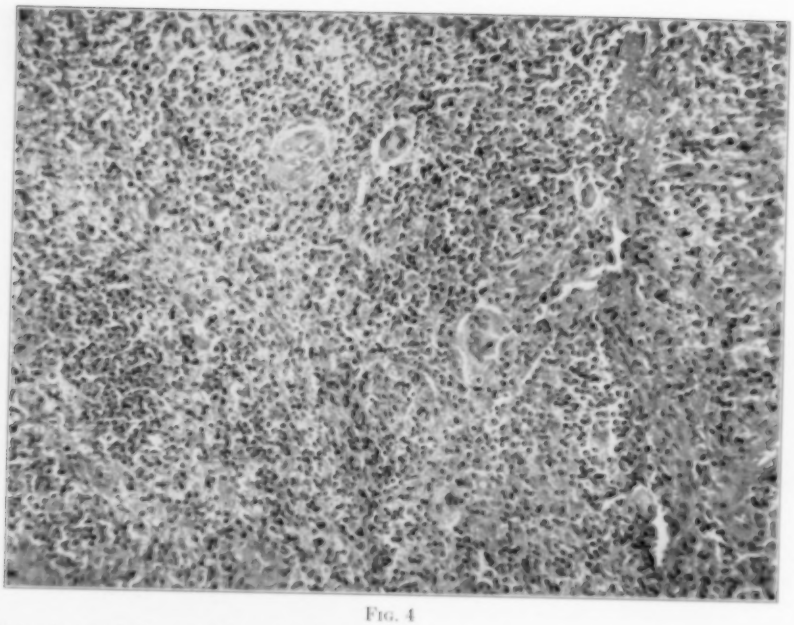

FIG. 4

Photomicrograph (hematoxylin and eosin, × 120). Giant cells predominate, and a dense accumulation of polymorphonuclear leukocytes is present just below and left of center.

*Pathological report*

*Gross:* The material consisted of a number of small fragments of greyish-yellow tissue with areas of reddish discoloration. These fragments were generally quite firm and averaged less than one centimeter in diameter. Small fragments of dense bone were also present.

*Microscopic:* The material was composed of granulation tissue. This tissue was heavily infiltrated by lymphocytes, large mononuclear cells, eosinophils, and polymorphonuclear leukocytes, the latter usually in dense focal accumulations (Fig. 4). A large number of giant cells of the foreign-body type were also present (Fig. 5). The most striking feature, however, was the presence of a large number of round or oval organisms which were usually surrounded by large clear zones. The diameter of these organisms varied from less than that of a red blood cell to approximately three times that size, and frequent budding was evident. The organisms were Gram positive and stained a deep red with periodic acid-Schiff's reagent technique (Fig. 6). The clear zone about these organisms did not stain. There were a few trabecular spicules of bone in the granulation tissue and also some fragments of dense reactive periosteal bone.

The diagnosis based on the pathological findings was chronic granulomatous osteomyelitis, probably cryptococcosis.

*Cultures:* When cultured on Sabauroud's glucose agar at a temperature of 32 degrees centigrade, the colonies were cream-to-brown colored and were moist and mucoid. The application of an India-ink preparation revealed thick-walled spherical organisms which varied considerably in size and which were surrounded by a thick capsule.

*Animal inoculations:* Five mice were injected intracerebrally and five intraperitoneally, with a saline suspension of a pure culture. Those injected intracerebrally died within three weeks and the autopsies revealed that their brains were covered by a massive gelatinous exudate. In each of these mice an organism morphologically typical of *Cryptococcus neoformans* was identified. All the animals injected intraperitoneally died within six weeks, the diagnosis being cryptococcus peritonitis and meningitis.

The immediate postoperative course of the patient was uneventful, and he remained afebrile. He continued to complain of pain about the right elbow, however, and a sputum culture obtained subsequently revealed the presence of *Cryptococcus neoformans*. The spinal fluid was normal.

*Subsequent Course*

Roentgenographic examination of the right elbow revealed a progressive increase in the size of the osteolytic lesion at the proximal end of the right radius. The left knee remained swollen, but there was no apparent

effusion. The patient had been receiving 300,000 units of penicillin and 0.5 gram of streptomycin intramuscularly daily. On February 5, 1954, however, he was started on a course of chlorotetracycline hydrochloride, 250 grams being given every six hours. On February 23, 1954, penicillin and streptomycin were discontinued.

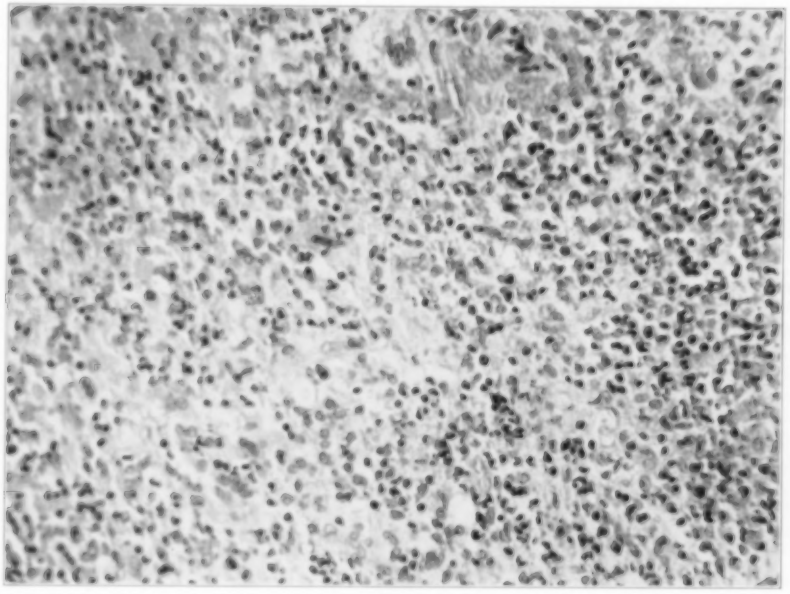

FIG. 5

Photomicrograph (hematoxylin and eosin, × 200). There is a marked proliferation of reticuloendothelial cells, and the giant cells contain many organisms. An isolated organism, appearing as a clear space with a central body, is present below and left of center.

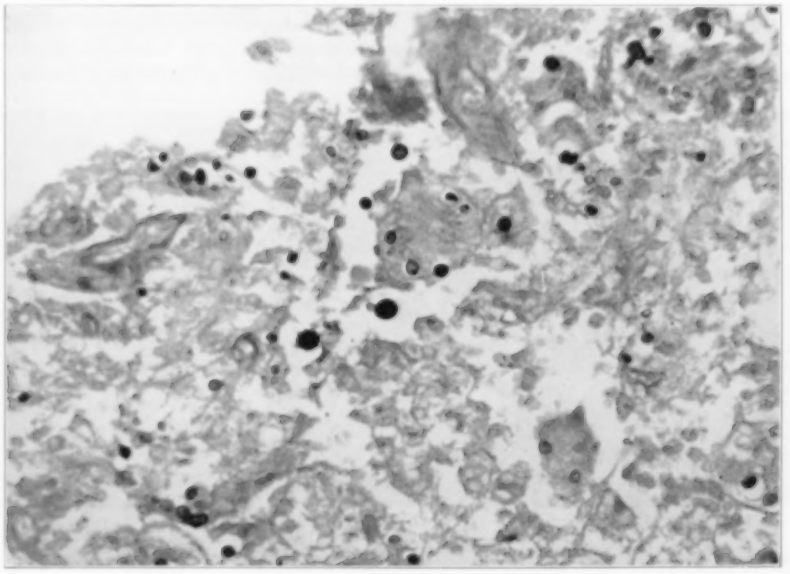

FIG. 6

Photomicrograph (periodic acid-Schiff's reagent, × 400). The variable size of the organisms is illustrated. A budding form is present in the center.

TABLE I

DISTRIBUTION AND INCIDENCE OF BONE LESIONS

| Bones | No. of Cases |
|---|---|
| Pelvis | 7 |
| Femur | 4 |
| Spine | 4 |
| Tibia | 3 |
| Skull (primary) | 2 |
| Clavicle | 2 |
| Humerus | 2 |
| Radius | 2 |
| Scapula | 1 |
| Rib | 1 |
| Talus | 1 |
| Joints | |
| Knee | 1 |
| Carpus | 1 |

Sensitivity studies made on the cultured *Cryptococcus neoformans* showed moderate sensitivity to cycloheximide and only minimal sensitivity to chlorotetracycline hydrochloride. On March 20, 1954, the patient complained of tenderness and swelling along the right sternal border just inferior to the sternoclavicular joint, but a roentgenographic examination of that area showed no abnormality. On March 23, 1954, he was started on a course of cycloheximide, the initial dose of twenty micrograms being progressively increased to forty micrograms given intravenously twice a day. On April 12, 1954, however, cycloheximide was discontinued because of severe nausea and vomiting; and on April 22, 1954, the patient was started on a course of thymol, a dose of 0.2 gram being administered every six hours. With the thymol the patient also received a saturated solution of potassium iodide, ten drops being given with milk every six hours. The parasternal lesion increased in size, and on May 3, 1954, five cubic centimeters of thick purulent material was aspirated. Bacteriological studies of this material revealed the presence of *Cryptococcus neoformans*.

On May 17, 1954, a presternal abscess was incised and drained, and thymol (1 to 10,000 solution) was inserted locally in the form of wet dressings. The abscess continued to drain for approximately two weeks, after which time healing by secondary intention occurred. A roentgenographic examination of the right elbow and of the right clavicle showed progressive healing of the lesions in both areas.

The results of repeated cerebrospinal-fluid studies on June 2, 1954, were negative, and the results of repeated sputum examinations were negative for fungi except on one occasion. A culture of bone marrow taken from the sternum on June 2, 1954, was also negative for fungus growth.

The patient remained afebrile and without symptoms, and there was a progressive gain in weight. On June 23, 1954, he was discharged from the Hospital with instructions to return for out-patient study.

The patient was seen again on July 12, 1954, at which time he was afebrile and had no complaints. The left knee was essentially normal, and there was a full range of motion. An examination of the right elbow revealed no abnormality. The surgical scars over the right clavicle and at the site of drainage at the right parasternal border were healed, and a roentgenographic examination of the right clavicle and radius showed

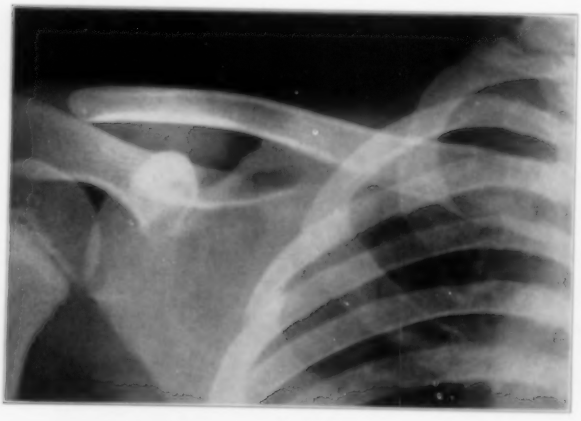

FIG. 7

FIG. 8

Fig. 7: A roentgenogram of the right clavicle made five months after curettement and the beginning of chemotherapy.

Fig. 8: A roentgenogram of the right radius made at the same time as that shown in Figure 6. There is residual periosteal reaction, but no evidence of active infection.

no evidence of bone destruction (Figs. 7 and 8). There was residual cortical thickening on the inferior aspect of the medial end of the right clavicle and along the margins of the proximal end of the radial shaft. The patient was requested to return for out-patient follow-up in approximately six weeks. He was to continue with thymol and the iodides on an out-patient basis.

## DISCUSSION

Because of the rarity with which this disease is encountered in orthopaedic practice, a brief review of the background and of the manifestations of the disease, with emphasis on its skeletal features, appears timely.

### *Epidemiology*

Cryptococcosis is a widespread disease, occurring throughout the world. Cases have been reported in the South Pacific, in South America, in Western Europe, and throughout the entire North American continent. Cases have occurred in the United States of America more frequently than in any other country, but within the United States there appears to be no regional variation in its occurrence.

The disease may occur in persons of all ages but most frequently occurs in young adults. Males predominate over females approximately three to one, and no racial group appears to be immune, although cases have been reported in Caucasians more often than in any other group.

### *Clinical Characteristics*

Infection due to cryptococcus may involve any organ or structure in the human body, and may be localized or generalized. When it is generalized, it usually terminates fatally as meningo-encephalitis. It is interesting to note that the disease frequently occurs in patients in whom a debilitating disease is already present. Cryptococcosis assumes several distinct patterns, and although it is not within the scope of this paper to discuss in detail all the forms in which it may occur, a brief summary of these forms appears essential for completeness and clarity.

1. *Pulmonary:* It is felt that the primary lesion in cryptococcosis almost always occurs in the lungs, although frequently this lesion is not apparent at clinical examinations. Linden and Steffen reviewed the literature on the pulmonary form of the disease and found nine cases of cryptococcal pneumonia in which there were no other manifestations of the disease. To this list they added one new report of localized pulmonary infection (in this case, pemphigus was already present). Pulmonary infection is usually not found alone, however, but is more common in association with the meningeal or generalized forms of the disease.

2. *Meningo-encephalitis:* The central nervous system appears more susceptible to infection by *Cryptococcus neoformans* than does any other organ or structure. Involvement in this region may be primary or secondary. The disease may mimic almost any form of intracranial lesion, and a diagnosis is established only by recovery of the organism from the spinal fluid or from material obtained by a surgical biopsy. This form of the disease almost invariably terminates fatally within three to nine months.

3. *Skin and mucous membranes:* Involvement of the epithelial structures by *Cryptococcus neoformans* may occur primarily, but more often it is secondary to involvement in other parts of the body. The lesions may appear as an acneform, papular, or nodular rash, and they often develop into ulcerations. Lesions of the mucuous membrane are seen rarely and, when encountered, are usually ulcerative.

4. *Generalized form:* The involvement of many organs and structures has been observed in a limited group of patients; this form of the disease is termed "generalized cryptococcosis". In patients with this form the diagnosis is rarely based on clinical findings alone but rather is applied by the pathologist after necropsy. In eleven of the cases of skeletal involvement reviewed in this paper the disease was of the "generalized" type.

*5. The skeletal system:* Due to the fact that there have been so few cases of skeletal involvement, observations concerning this form of the disease are justifiably incomplete; nevertheless, certain characteristic features of the bone lesions have been described. Almost every bone in the skeleton has been involved, and Table I lists the individual bones according to the frequency with which they have been infected, as recorded from the case studies.

Most frequently bone lesions are associated manifestations of the meningeal and "generalized" form of the disease. Of the nineteen established cases exhibiting skeletal cryptococcosis, eight were of a localized variety and eleven cases exhibited bone involvement in association with generalized or central-nervous-system cryptococcosis.

In a patient with skeletal cryptococcosis, the initial symptom is usually swelling and tenderness in the soft tissue adjacent to the affected bone. Persistent mild-to-moderate pain, particularly in the weight-bearing bones, is not infrequent. There is usually no local redness, but there may be a moderate local elevation in temperature. Sinus formation is rarely seen, and the systemic reaction is usually mild with a temperature elevation of one to three degrees Fahrenheit, associated with mild malaise, fatigue, and weight loss. With involvement of more vital organs, more severe symptoms may appear, and these symptoms frequently overshadow the local signs and symptoms resulting from the bone involvement.

In their appearance, as shown by roentgenograms, the bone lesions produced by cryptococcosis are similar to those produced by blastomycosis and coccidioidomycosis. The lesions may be multiple but individually they are discrete, and they are almost invariably osteolytic and may or may not stimulate a periosteal reaction. The osteolytic areas characteristically grow by uniform enlargement; and healing, when it occurs, is slowly progressive with restoration of the normal trabecular pattern and disappearance of the periosteal reaction. In contrast to these lesions, the bone lesions caused by actinomycosis are usually secondary to soft-tissue involvement, as Carter points out, and they exhibit a greater tendency to periosteal reaction. The destructive areas in these lesions are adjacent to areas of reactive bone, and as a result the bone has a riddled appearance on the roentgenograms, making it possible for the trained examiner to make a reasonably accurate differential diagnosis.

The response of tissue to the presence of *Cryptococcus neoformans* is extremely variable. There may be little or no response, as frequently happens in the meningeal form of the disease, when large masses of organisms may occur in the leptomeninges without any discernible reaction on the part of the host. There may be an inflammatory reaction, consisting only in a lymphocytic infiltration of a completely non-specific nature or this may be accompanied by an infiltration of polymorphonuclear leukocytes. The more extreme reaction, which occurred in our case, consists in an intense proliferation of granulation tissue with frequent phagocytic giant cells (Figs. 6 and 7). Occasional micro-abscesses and even "granulomata" are formed, and the bone may be expanded peripherally. As noted, the organism may be demonstrated readily if the periodic acid-Schiff's reagent technique is used on tissue sections (Fig. 8).

*Cryptococcus neoformans* is a true blastomycete or budding fungus, and varies considerably in size, ranging from five to twenty-five micra. It is round or oval, thick-walled, and surrounded by a heavy gelatinous capsule.

When cultured on Sabouraud's agar at room temperature or at 37 degrees centigrade, a yellowish-brown, moist mucoid colony is produced. According to Conant, sugar fermentations are so variable that their use for identification is precluded.

The diagnosis of infection due to *Cryptococcus neoformans* can be established only by (1) culture of the fungus from infected material; (2) identification of the organism in material obtained by biopsy; and (3) reproduction of the disease in experimental animals, an isolated organism being used. Confirmation of the diagnosis of a parti-

TABLE II

LOCALIZED BONE INVOLVEMENT IN CRYPTOCOCCOSIS

| Author | Bone | Treatment | Outcome |
|---|---|---|---|
| 1. Brewer and Wood | Spinous processes thoracic and lumbar vertebrae | Local incision of both lesions | Well one year |
| 2. Kessel and Haltzwart | Knee (Lesions in both breasts) | Amputation | Well one year |
| 3. Ducuing, Bassal, and Miletzky | Orbit | Local curettage | Well eight months |
| 4. Dienst | Tenth rib | Local resection<br>Potassium iodide | Well six months |
| 5. Jesse | Inferior ramus of the right pubis | Penicillin<br>Sulfadiazine<br>Local resection | Well one year |
| 6. Fisher—Case I | Ilium<br>(Presternal abscess) | Local excision of lesion of ilium; repeated aspiration of presternal abscess with local application 3.5 per cent iodine | Well one and one-half years |
| 7. Leopold | Talus and carpus<br>(Pulmonary moniliasis) | Cryptococcus vaccine | Bone lesions healed |
| 8. Gosling and Gilmer | Radius<br>Clavicle<br>(Presternal abscess and pneumonia) | Local curettage of clavicle<br>Tetrachlorocycline<br>Cycloheximide<br>Potassium iodide<br>Thymol | Well twenty months |

cular bone lesion can be made only by culture of material obtained from that lesion.

It is possible that many cases of infection due to *Cryptococcus neoformans* go undiagnosed. The disease is encountered so rarely that the clinician may fail to consider it as a possible cause of infection. This failure would lead almost invariably to improper laboratory handling of the material obtained for culture or histopathological study, which in turn would result in incomplete or erroneous diagnosis.

*Therapy*

It is beyond the scope of this paper to discuss the therapeutic measures which may be used to treat the "generalized" or central-nervous-system form of the disease. For those interested in an evaluation of the many agents which have been used to treat cryptococcosis in general, reference is made to an excellent brief review of the subject by Evans and Harrell. A forthcoming report by Ettledorf will review the use that has been made of thymol and iodides in a number of cases, including the case reported by the authors.

It is difficult to recommend any specific therapy for cryptococcosis because such therapy is still in an experimental stage. In their review of the literature Evans and Harrell list forty-three different therapeutic methods which have been tried. Long remissions often occur during the course of this disease, and this makes evaluation of any specific therapy difficult. Cycloheximide and 2-hydroxystilbamadine are being studied at present and, therefore, are the drugs most frequently recommended by students of the disease. At the recent Third Annual Symposium on Antibiotics it was reported that two new antibiotics obtained from a streptomycete were effective against *Cryptococcus neoformans* in mice.[10, 15]

In our case there is circumstantial evidence that thymol and iodides were of value. Thymol (a phenol derivative) and the elemental iodides are fungicidal agents when applied

locally, and, therefore, their use in a cutaneous disease has a rational basis. (Parental use of these compounds is empirical.) It has been generally accepted that the iodides have a lytic effect upon granulomatous tissue; and this effect was the rationale for their use in syphilis, as well as the contra-indicating factor against their use in tuberculous infections. Thymol has proved efficacious in some cases of actinomycosis, and, therefore, a trial in other fungus infections is indicated.

## CONCLUSIONS

The prognosis for patients in whom skeletal cryptococcosis is associated with "generalized" or meningeal involvement is poor, and there have been no recorded survivals of such patients in spite of therapy. In contrast to the fatal results in this group, however, the results in patients with localized bone disease have been good; these patients have all been well at the time their cases were reported. Table II lists these cases, describing the bones involved and the therapy employed. It is interesting to note that in all but two of these cases surgical extirpation of the disease locally was performed with apparently good results. In the case presented by Leopold cryptococcal infection of the talus and carpus was further complicated by the presence of pulmonary moniliasis. The patient in this case received vaccine therapy, but local excision of the diseased bone was not performed. The bone lesions apparently healed, but no change occurred in the pulmonary lesion. In the authors' case the clavicular lesion was treated by local curettement while the radial lesion was left untouched. Both lesions healed satisfactorily, but an analysis of the cause of this satisfactory outcome was clouded by the fact that several antibiotic and chemotherapeutic agents had been used.

After reviewing this small series of cases, the authors feel that the prognosis for patients with localized bone lesions is good regardless of the therapy employed. They also feel, however, that surgical removal of the diseased bone will enhance healing and will lessen the possibility of dissemination of the disease.

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# Arterial Injury in Orthopaedic Surgery

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Although vascular injury is not a common problem in civilian orthopaedic practice, the orthopaedist should have a knowledge of and a working experience with vascular reparative surgery. The vascular injuries which may confront the orthopaedist may be caused by fracture fragments, crushing injuries, lacerations, puncture wounds, missile wounds, and damage to a major vessel during an operation. When vascular injury is encountered, a true surgical emergency exists; for delay or indecision in regard to the course of treatment may easily lead to the loss of an extremity or even to the loss of life. As Janes and Ghormley have so aptly stated, the four important principles to be followed in managing a vascular injury are: (1) do not delay, (2) do not elevate, (3) do not heat, and (4) do not refrigerate. The time elapsing between injury and repair is most important. As shown both clinically and experimentally, repair within six to eight hours increases the chance for success.[12]

The types of injury which may occur are: complete severence of a major vessel, transverse or longitudinal laceration, puncture wound, hemorrhage into the arterial wall, and segmental arterial spasm. Except in the case of proved arterial spasm, surgical exploration and repair of the vessel is indicated. The diagnosis of arterial spasm can usually be substantiated, and the circulation to the extremity can be improved promptly by means of sympathetic-nerve block with local anaethesia. When reasonable doubt of the existence of simple arterial spasm exists, exploration should be performed. It is not dangerous.

Superficially, the diagnosis of a lacerated major artery or its complete transection may appear to be simple, but this is not always true. Completely transected muscle arteries retract and often so seal themselves with a clot that exsanguination is prevented. However, bleeding from a lacerated artery may be profuse and continuous. The degree of hematoma may not be indicative of the amount of blood lost or of the presence or absence of transection, because the size of the hematoma is dependent upon the size of the extremity, the amount of blood which has escaped into it, and finally, upon whether or not there has been a penetrating wound. With open fractures, no hematoma may be present, even though the femoral artery may be completely severed (Case 5). The cardinal signs of major vascular injury in the extremity are the absence of pulses and the general appearance of the extremity. A complete severance of the major arterial channel leaves the distal portion of the extremity white and cool. The capillary return is very slow in comparison with that on the normal side, and there is slow venous filling distal to the injury. Within one to two hours after injury to a major artery, a diminution of sensation distal to the injury usually takes place; complete anaesthesia eventually occurs, and a painful extremity becomes painless.

Crushing injuries to the hands and feet, which are common industrial accidents, may at times present major vascular problems. In such injuries, many small arteries, or even the major arteries, of the hands and feet may be ruptured. Such injuries cause tense swelling of the involved part, particularly when no compounding wound is present. This type of injury is a real surgical emergency; for unless something is done to relieve the ischaemia of the involved part, permanent disability and even loss of the extremity may take place. In such cases prompt and adequate fasciotomy is extremely important (Case 2).

Another problem which may be seen by the orthopaedist is that of vascular injury which has not been recognized for some time. This problem usually evolves itself around

two well recognized entities—the false aneurysm and the arteriovenous fistula. The false aneurysm is the result of a laceration of the vessel wall, the subsequent hematoma, and, finally, the organization of the hematoma into a pulsating sac which communicates with the artery. The aneurysm will usually continue to enlarge slowly and, if it is untreated, it eventually ruptures or obliterates the flow of blood in the vessel distal to the aneurysm. Such an aneurysm may occur from a closed fracture (Case 6). The arteriovenous fistula occurs from injury to a major artery and its companion vein. The signs and symptoms of the arteriovenous fistula are well known. Waiting for a collateral circulation to develop is often foolhardy, for waiting permits the aneurysm to grow and makes repair more difficult. Actually, the collateral circulation develops promptly and adequately in cases of arteriovenous fistula, so that repair can be safely effected whenever the diagnosis is made. Endoaneurysmorrhaphy, graft-replacement, and quadrilateral resection are the three effective means of handling arteriovenous fistulae. Quadrilateral resection is safe providing that there is adequate backflow from the distal segment of the artery.[8] If backflow is slow, re-establishment of continuity is mandatory. In the case of false aneurysm, however, it is probably much safer to attempt to restore the major arterial channels whenever it is possible to do so.

Pathological changes involving the bones, joints, and muscles of the extremities may also present a vascular problem to the orthopaedic surgeon. Local resection of tumors may necessitate vascular grafts, and in wide local resections, major arterial injury can easily occur. The case of myositis ossificans involving the femoral artery (Case 1) is an interesting example of how the orthopaedist can be confronted with a serious arterial problem. Injury to one of the major abdominal vessels during removal of an intervertebral disc demands prompt and decisive action on the part of the surgeon in order to preserve the life of the patient. The use of Kirschner wires and Steinmann pins may lead to difficulty with a major arterial channel (Case 3). The use of the intramedullary nail can also produce a vascular complication. The problem of secondary hemorrhage from a ligated artery following amputation may be a vascular problem (Case 4) and at times may necessitate emergency surgery in an area which is not well known to the orthopaedist. Necrosis of the tibialis anterior from injury to the anterior tibial artery has been recognized and previously described.[3, 6] Brachial-artery injury from dislocation of the elbow or supracondylar fracture of the humerus has been reported recently.[15]

When a major vascular injury has been diagnosed or is strongly suspected, the course of action on the part of the surgeon should be clear. If there has been major blood loss and if shock is present, the surgeon should direct his action to careful and adequate control of further blood loss. This can be done by manual pressure, packing of the wound, careful application of the hemostat to the bleeding vessel, or, as a last resort, the application of a tourniquet. The dangers of the tourniquet are well known, and it should be remembered that with its use all possible collateral circulation to the involved extremity is obliterated. Elevation of the extremity may further increase the ischaemia. The use of heat is contraindicated, and, as has been pointed out by several observers, the application of cold is probably of little benefit and may even be detrimental.[5, 10, 11]

When bleeding has been controlled, attention should be turned to the resuscitation of the patient. When the patient's general condition is deemed satisfactory, adequate exposure of the involved vessel should be undertaken. There is no substitute for complete and adequate exposure when dealing with a problem of this type. The proximal portion of the vessel involved should be exposed and controlled well proximal to the site of injury. This will frequently prevent considerable loss of blood and will also allow more careful dissection of the injured vessel. When the injured portion of the vessel has been examined, decision as to the nature of repair can be made. Small lacerations can usually be repaired with arterial silk. When the vessel has been transected, or almost transected, an end-to-end anastomosis should be performed. The vessel must be inspected very carefully and all

damaged portions must be resected or clotting at the site of anastomosis may follow. If the defect is so great that normal appearing arterial ends cannot be anastomosed, either a venous graft, or, if available, a homologous arterial graft can be used. The techniques of arterial anastomosis with the everting mattress suture, the over-and-over suture, or the interrupted mattress suture have been known for a long time.[1, 2] For repairing simple lacerations, the interrupted suture is probably the best. No. 00000 or No. 000000 arterial silk should be used. The use of arterial and venous grafts is growing and the value of their use is becoming established.[2, 13, 16, 17]

It is important to know which vessels require restoration, because any arterial anastomosis or grafting is both a tedious and a time-consuming procedure. The techniques of arterial repair in use since the Korean conflict have become well known, and the fact that they can be done successfully has become well established.[5, 19] It has been stated that almost any vessel of the upper extremity may be ligated with impunity [6]; this is not true. In battle injuries seen in World War II, after ligation of the brachial artery below the profunda, 25 per cent of upper extremities required some form of amputation. It is well known that after ligation of the common femoral artery and the popliteal artery a high incidence of gangrene occurs. The degree of associated injury to the surrounding structures influences the survival of an extremity following ligation or repair of its main arterial channel. Tissue damage in proximity to the arterial injury obliterates important collateral vessels. When a fracture is associated with a transected major artery, the prognosis for the extremity, even with arterial repair, is grave (a 50 per cent extremity loss), and after ligation it is worse (a 60 to 70 per cent extremity loss).[4, 19] Actually the difference between the effectiveness of ligation and vascular repair is much greater than these figures indicate. Even though an extremity may live following ligation, it is so often rendered useless by fibrosis and atrophy that amputation eventually becomes necessary. However, this rarely occurs after arterial repair—a living extremity is a useful extremity after successful vascular repair; whereas, a living extremity is often a useless one after ligation. Repair of the common femoral artery and the popliteal artery is mandatory, and it is probably safer to repair the superficial femoral artery and the brachial artery in acute injuries.[7] Should both the anterior and posterior tibial vessels be injured, one must be restored. In general, we must consider that in any major vascular injury, a successful repair of the involved vessel will increase the chances of survival of the extremity. There are, of course, instances when ligation is necessary because of infection (Case 3) or, as in the case of arteriovenous fistula, when collateral circulation may be quite adequate.

Following repair of a major arterial channel for acute injury, a prompt return of the peripheral pulses is an important sign that the repair has been satisfactory.[12] However, a return of pulses in the hands and feet may, in some cases, be delayed for from one to four hours.[19] The absence of a peripheral pulse should still lead one to search the anastomosis for the possibility of clotting.

The use of anticoagulants postoperatively should be undertaken only after careful consideration, for much difficulty from their use may arise in the patient recently operated upon. Paravertebral block has been advocated following arterial repairs; however, it should be remembered that in the completely transected artery a periarterial sympathectomy has been accomplished in the distal portion of the vessel. Rest, observation, and occasionally plaster splinting of the extremity are all that are necessary during the postoperative period.

The following group of cases has been seen on the Barnes Hospital Orthopaedic Service during the past few years. These cases are presented as examples of some of the types of vascular injury that may confront the orthopaedic surgeon. These do not, in any sense, represent all types of injury; for we have not, in this period of time, seen injury to the brachial artery secondary to injury in the region of the elbow; nor have we been confronted recently with an arteriovenous fistula.

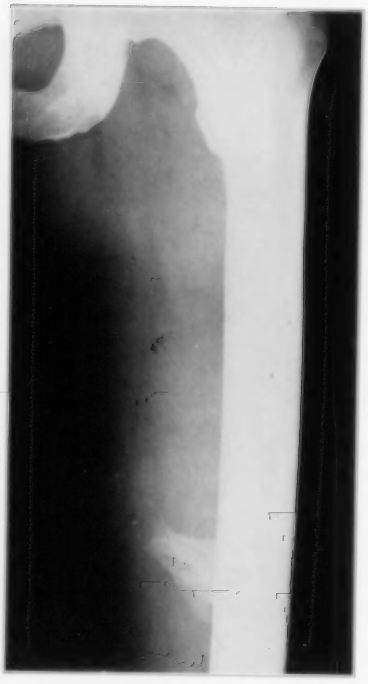

FIG. 1-A

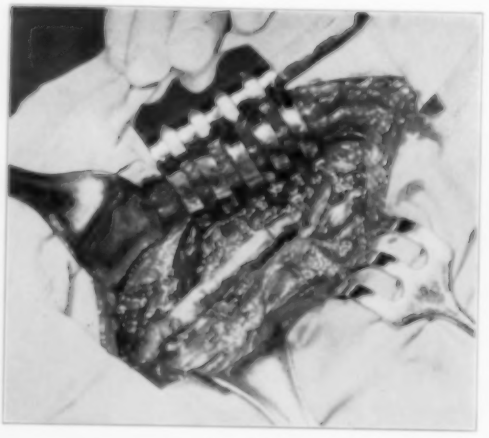

FIG. 1-B

FIG. 1-C

Figs. 1-A, 1-B, and 1-C: Case 1. Illustrations show the myositis ossificans, the homologous arterial graft in place, and the postoperative status of the patient's left lower extremity.

CASE 1. C. H., a forty-year-old white male, was kicked in the medial side of the left thigh during a soft-ball game in July 1953. Later he consulted an orthopaedic surgeon concerning a mass in the medial side of the thigh. On examination, a seven-by-four centimeter mass was palpable in the medial side of the left thigh. Roentgenographic examination confirmed the diagnosis of myositis ossificans. There were no symptoms or physical findings suggestive of major vascular involvement.

On March 24, 1954, excision of the myositis ossificans was undertaken because of persistent pain, and the mid-portion of the superficial femoral artery and vein were found to be involved in the pathological process. During the operation, the friable wall of the femoral artery was torn. It was immediately apparent that an extensive vascular repair would be necessary in order to re-establish the continuity of the involved vessel. Since suturing of the torn vessel was not feasible because of its pathological state, the diseased portion of the vessel was resected. The defect in the femoral artery was replaced by a two-and-an-eighth inch freeze-dried arterial homograft. A continuous everting mattress suture of No. 00000 arterial silk was used. Because of a failure of prompt return of pedal pulses, the distal anastomosis was redone; following this, excellent pulsation in the pedal arteries returned. The superficial femoral vein was ligated.

Antibiotics, bed rest, and no anticoagulants comprised the postoperative management. A follow-up examination one year later revealed normal pulsations in the foot on the involved side, but the myositis ossificans had recurred. There were no symptoms related to the vascular supply of the extremity.

CASE 2. L. Q. P., a lead miner, sustained at 3 A.M. on May 12, 1954, a crushing injury to the left foot when he was caught between two mining cars. He was promptly sent to St. Louis, where he arrived at 12:45 P.M. on May 12, 1954. Examination revealed extremely tense swelling of the left

FIG. 2-A

FIG. 2-B

FIG. 2-C

Figs. 2-A, 2-B, and 2-C: Case 2. Illustrations show a tensely swollen foot with early bleb formation, the lateral fasciotomy, and secondary wound closure. A fasciotomy and closure were done on the medial side of the foot.

foot. The toes were white and cold, and the capillary return was slow. There was a marked decrease in sensation over the entire foot to the level of the ankle. There was a one-centimeter compounding wound over the distal inch of the left tibia. Roentgenographic examination revealed fractures of the calcaneus, the talus, the navicular, and the medial malleolus.

It was immediately apparent that there was severe vascular insufficiency in this foot. At 2:30 P.M. on May 12, 1954, under spinal anaesthesia, a fasciotomy was done on both the medial side and the lateral side of the foot and ankle. The posterior tibial artery was found to be completely transected just as it entered the plantar surface of the foot. This vessel was ligated. A large amount of hematoma was evacuated on both sides, and immediately satisfactory circulation was restored to the distal part of the foot. Both wounds were left open and were packed loosely with dry, fine-mesh gauze.

The postoperative course included slight elevation of the extremity, intermittent application of wet dressings to the wound, and antibiotics. On May 21, 1954, the medial wound was closed, and on June 2, 1954, the lateral wound was closed. Both wounds healed satisfactorily, and the patient was discharged on June 15, 1954. In June 1955, it was reported by his surgeon that the patient was walking well, although he had some residual stiffness of the foot. The patient had returned to work.

CASE 3. C. C., a forty-year-old white male, was seen because of non-union of a supracondylar fracture of the left femur. On October 17, 1951, under general anaesthesia, an iliac-bone graft was applied to the site of non-union after the bone ends had been freshened and squared off. Steinmann pins were then inserted into the proximal portion of the tibia and the proximal fragment of the femur. The pins were incorporated in a single spica cast, and the patient was discharged on October 25, 1951, following an uneventful postoperative course.

On November 4, 1951, the patient was re-admitted because of blood staining of the cast during the previous three days. On admission, the cast was removed, and a moderate amount of clotted blood was seen adjacent to the medial side of the proximal Steinmann pin. The proximal pin was cut and removed; whereupon there was immediate hemorrhage from the medial pin hole. Since injury to the femoral artery seemed most likely, exploration of the vessel was immediately undertaken under a general anaesthesia. The femoral artery was exposed proximal to the site of the pin, and, upon dissection distally, the superficial femoral artery was found to be eroded through half its circumference. The vein was not involved. Since there was chronic infection along the pin tract and in the area of the eroded vessel, ligation of the superficial femoral artery was done. The postoperative course was uneventful except for a mild low-grade infection which was entirely

healed within a month. No circulatory difficulties developed in the extremity of the affected side. Union of the fracture took place, and a serviceable extremity was the result. It was considered that the slough of the arterial wall might possibly have been caused by the heat generated in the pin during its insertion.

CASE 4. F. A. N., a white male, fifty-six years old, was seen with reticulum-cell sarcoma of the trochanteric region of the left femur. He had been previously treated with extensive x-ray therapy. Following this a pathological fracture occurred. This was treated with a Key nail; however, the wound broke down and failed to heal. A *draining* sinus persisted from June 1953 until March 1954. On March 23, 1954, the patient was admitted to the Hospital again because of persistent and severe pain. On April 22, 1954, because of the large, *foul, draining* sinus, excision of the head, neck, and trochanters of the femur was done; however, the tissue was extremely avascular, and the wound failed to granulate. Subsequently, on July 15, 1954, disarticulation of the hip was done, but again the wound failed to heal. At the time of disarticulation the femoral artery was *doubly* ligated and transfixed with No. 1 chromic catgut.

On August 31, 1954, the dressing was suddenly soaked with bright red blood, and inspection of the wound revealed a slough of the ligated femoral artery about one and a half inches proximal to the inguinal ligament. The patient was immediately taken to the operating room, and through a left paramedian lower abdominal incision, the common iliac artery on the left side was ligated with heavy silk sutures. The common iliac vein was similarly ligated. This ligation satisfactorily controlled the hemorrhage. The patient eventually expired on October 30, 1954, with widespread metastatic lesions.

CASE 5. L. C., a white male, twenty-six years old, was in an automobile accident at 12:30 A.M. on May 12, 1953. Emergency treatment was given in another hospital, and the patient was sent to St. Louis by ambulance, at which place he arrived at approximately 6 A.M. on May 12, 1953. On admission, the patient was found to be in shock, with a pulse of 140 and a blood pressure of 80 systolic and 60 diastolic. The following injuries were present: a compound fracture of the left femur with a wound over the apex of the femoral triangle, a compound fracture of the left tibia, and a comminuted fracture of the left scapula. Examination revealed a cool, white foot with poor capillary return on the left side. No pedal pulses were palpable, and, although there was little or no bleeding from the compound wound of the thigh, rupture of the femoral artery was suspected.

Attention was immediately directed to treatment of the shock, and by 8:15 A.M. on May 12, 1953, the patient had received 1,500 cubic centimeters of whole blood and was considered to be a satisfactory candidate for operation. At 9:30 A.M., exploration of the femoral artery and vein was carried out, and both were found to be completely torn below the profunda. Very extensive muscle damage was also present in the thigh. The continuity of the artery was re-established by means of an end-to-end anastomosis with No. 00000 arterial silk. The wound was debrided, and the fracture fragments were allowed to override in order to remove any tension from the vascular repair. The wound was closed. Following repair, the pedal pulses were not palpable; however, the capillary return was improved and was considered satisfactory. Postoperatively the patient was placed in a balanced suspension, five pounds of skeletal traction being used. Continuous paravertebral block was employed along with antibiotics and anticoagulants; however, in spite of all that could be done, on May 19, 1953, the foot and lower two-thirds of the leg were obviously gangrenous. On May 20, 1953, a supracondylar amputation of the femur was carried out, and the fracture of the femur was stabilized with a Lottes nail.

This case again emphasizes the grave prognosis for an extremity when severe vascular injury is complicated by fracture.

CASE 6. C. E. R., a seventy-year-old white male, fractured the right tibial plateau and head of the fibula on April 21, 1955, when he fell from a ladder. He was seen six hours after his injury and a very severe hemarthrosis of the right knee was present. There was marked oedema of the foot and leg; however, circulation to the foot appeared to be satisfactory. No neurological changes were found. Aspiration of the knee relieved the pain, and a toe-to groin plaster cast was applied. The hospital course was uneventful. On May 24, 1955, the cast was changed and the extremity appeared to be satisfactory except for the persistence of some moderate oedema of the leg and foot.

On June 9, 1955, the patient returned to the orthopaedic clinic, and when the cast was removed, a large pulsating mass was seen in the region of the head of the fibula. A bruit was easily heard. In addition, complete peroneal-nerve palsy had developed. A posterior tibial pulse was present, but the dorsalis pedis pulse was absent. The patient was admitted to the hospital the same day, and an arteriogram (thirty cubic centimeters of 25 per cent miokon) confirmed the clinical diagnosis of a false aneurysm of the anterior tibial artery.

On June 10, 1955, exploration of the area was carried out under general anaesthesia. Following isolation of the peroneal nerve and control of the popliteal artery proximally, the aneurysm sac was opened and evacuated. The fracture fragments of the fibula formed part of the wall of the aneurysm which contained 1,000 cubic centimeters of clotted and fresh blood. The defect in the artery was found to be four to five millimeters in diameter and was located exactly in the bifurcation of the popliteal artery. Repair of the arterial defect was carried out with No. 00000 arterial silk, since ligation of the anterior tibial artery could not have been accomplished without also seriously constricting the lumen of the posterior tibial vessel. The

FIG. 3-A

FIG. 3-B

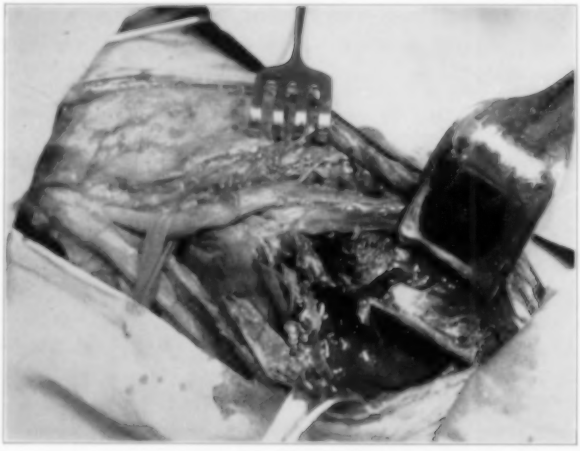

FIG. 3-C

Figs. 3-A, 3-B, and 3-C: Case 6. Illustrations show the swollen right leg, the bulge of the aneurysm in the region of the head of the fibula, and the aneurysm cavity (arteriogram). The peroneal-nerve branches were found in the wall of the aneurysm.

wound was closed with catgut and was drained through two posterior stab wounds. Wound healing was uneventful, and on June 18, 1955, after some of the oedema of the foot had subsided, good dorsalis pedis and posterior tibial pulses were palpable. The patient is now ambulatory and wearing a drop-foot brace.

CASE 7. G. W. C., a forty-year-old white male, received a gunshot wound through both thighs while deer hunting on November 5, 1951. Fractures of the distal third of the right femur and of the femoral condyle of the left femur were present. The patient had been previously treated by means of skeletal traction and packing of the wounds with petrolatum gauze. On November 11, 1951, the patient was transferred to St. Louis because of gangrene of both feet. Upon admission to the hospital, a fist-size pack of petrolatum gauze was found in the left thigh lying against the femoral artery. From the right thigh a similar pack was removed and the femoral artery was visible but not pulsating. On November 20, 1951, an above-the-knee amputation was carried out on the left side, and pathological study of the specimen revealed an organized thrombus of the anterior tibial artery. On November 27, 1951, a below-the-knee amputation was necessary on the right side.

It was thought that the tight packing of these wounds possibly played a role in producing the avascularity of the extremities distal to the wounds.

A fracture associated with disruption of the main arterial channel to the extremity is probably the most serious of vascular injuries that can confront the orthopaedic surgeon. In the past, this has very often resulted in the loss of part or all of the involved extremity. The principle of treatment has not yet been established; however, it is possible that when stabilization of the fracture site primarily by the intramedullary nail can be done, the chances of survival of the extremity may be increased. Following stabilization of the fracture, reconstitution of the arterial channel can be undertaken.

When a fracture has produced a tear of a large artery, there almost always occurs extensive soft-tissue injury, disruption of collateral channels, and severe damage to the arterial wall at a considerable distance from its actual site of disruption. Since it is necessary to remove all damaged portions of the artery, a long graft may be necessary in order to re-establish arterial continuity. It has been suggested that a long "shunt-graft" may be a simpler solution to bridging the defect than the end-to-end graft that has been employed in the past.[14] Such grafts, with end-to-side anastomoses, have been successfully used in by-passing long arteriosclerotic segments in the femoral artery. This type of graft can extend from the common femoral artery to the popliteal artery if necessary. The advantage of such a graft would be that some collateral vessels might be saved in not doing an extensive mobilization of the damaged ends of the torn artery.

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# Quadriceps Cineplasty in a Patient with Bilateral Lower-Extremity Amputations

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The concept of the cineplastic procedure was first employed in the last decade before the turn of the century by Vanghetti in Italy and Ricard, his precursor [3], in France, who reported an improved version of his earlier procedure in 1905 [12]. The major work with cineplastic procedures, however, came after the turn of the century and was done for the greater part in Italy and Germany [3]. In 1910 Codivilla [4, 5] of Bologna reported a case of a foot amputation which he cinetized by making two subcutaneous knobs, one was of the extensor tendons anteriorly and the other of the Achilles tendon attached to a part of the calcaneus posteriorly. The pad over the end of the tibia was made to move back and forth by the action of these muscles, and the knobs helped to retain the prosthesis as well as to impart some ankle motion to it. Within a few years, Galeazzi, Dalla Vedova, and Pieri [8, 9] had reported additional extremities which were cinetized in accordance with the club-motor principle, a movable fascial cuff being provided over the stump end. Dalla Vedova also reported cases of knee amputations in which he used the sliding patella over the end of the reconstructed femoral condyles to activate the leg of the prosthesis.

Bosch Arana used various methods to cinetize the muscles of the lower extremity. He made skin-lined tunnels through loops of muscles or tendons which extended beyond the bone end in the stumps of some amputees. In others he made subcutaneous knobs of the muscles which he encircled with a ring, clamp, or cord.

Putti [10, 11] in a report of several cases, described a partially successful case in which he added a suprapatellar transverse tunnel through the quadriceps to a flexor-extensor loop over the stump end.

Sauerbruch used skin-lined tunnels of either the quadriceps or hamstring muscles or both to produce motors for movement of the leg. Many German surgeons adopted this same method.

Blencke in 1916 reported a case in which he made a loop motor of the quadriceps and hamstring muscles over the end of a mid-thigh stump. He attached this to a cam on the knee axle of the artificial limb for extension of the leg.

Since shortly after World War I, few reports of lower-extremity cinetization have been made. A recent application of the principle of cinetization was employed by Rounds in 1948 as a temporary measure to retain quadriceps function in a patient who had sustained multiple gunshot wounds of the lower extremity with loss of the lower third of his quadriceps. The cinetized quadriceps was employed to extend the leg until a successful quadriceps repair was performed fifteen months later.

Because of comparative success in the use of cineplasty in rehabilitation of upper-extremity amputees at Walter Reed Army Hospital [15, 16, 17], it was thought that there might be a place for the procedure in the bilateral above-the-knee amputee who had an end-bearing stump. An adequate force-length curve could be obtained from a successful muscle motor of the quadriceps, so that the ability to extend the knee of the prosthesis and hold it in extension would produce some improvement in the patient's ability to rehabilitate himself.

A seventeen-year-old male sustained traumatic amputation of the right leg two inches below the knee and of the left through the mid-thigh on September 17, 1952, when he slipped into a corn picker. He was

FIG. 1

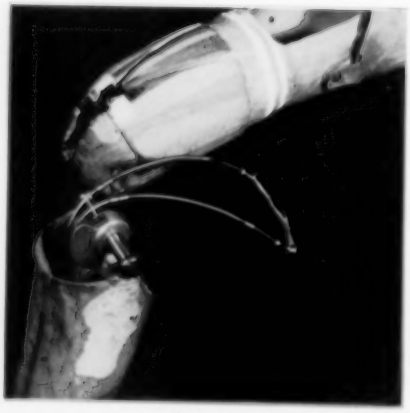

FIG. 2

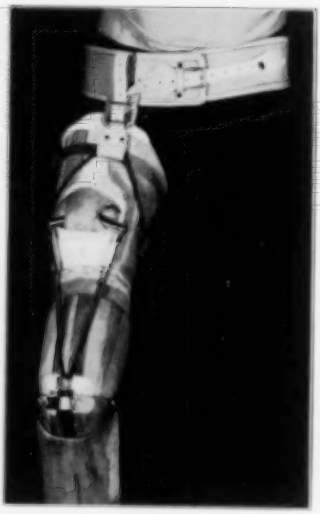

FIG. 3

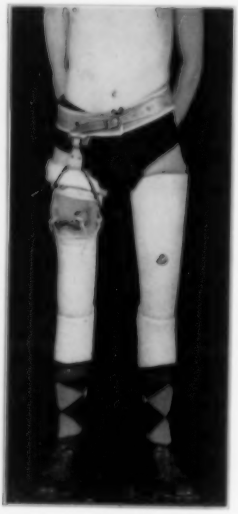

FIG. 4

Fig. 1: Above-the-knee end-bearing stump with stainless-steel pin in cineplastic tunnel.

Fig. 2: Details of cables attached to pin to extend leg.

Fig. 3: Unfinished artificial leg showing pin in tunnel and cable-housing uncovered.

Fig. 4: Anterior view of quadriceps cineplasty in a bilateral above-the-knee amputee wearing the modified end-bearing prosthesis on the right and a suction-socket prosthesis on the left.

admitted to Walter Reed Army Hospital on October 13, 1952, with open stumps. On October 20, 1952, a Gritti-Stokes amputation stump was made on the right, and a nine-inch above-the-knee stump was made on the left. After the stumps were healed, the patient was fitted with an end-bearing prosthesis on the right and a suction-socket prosthesis on the left.

Because of instability, which is usual in bilateral above-the-knee amputees, the patient requested that a cineplastic tunnel be made on his right thigh. He had seen and been impressed with the usefulness of tunnels on the cinetized arm amputees in his ward. On February 7, 1953, a quadriceps cineplastic procedure was performed; the technique described by Spittler[12] for a biceps cineplasty was used.

A skin flap, measuring five inches on each side, was outlined on the anterior surface of the thigh approximately five inches above the end of the stump. This flap, including the fascia of the underlying quadriceps was elevated following incision on the proximal, distal, and medial sides. The lateral side having been left intact served as the "hinge". The edges of the proximal and distal sides were then brought together and the middle three inches were sutured to form a tube lined with skin and with openings on the medial and lateral ends. Next, the quadriceps femoris tendon was severed above the patella and brought out through the wound. The lower portions of the vastus medialis and vastus lateralis were separated from the tendon. The muscle mass was pierced horizontally above the tendinous portion and dilated enough to accommodate the skin tube. The cut portion of the muscle was imbricated to provide a smooth end and to prevent re-attachment.

The skin tube was then drawn through the opening in the muscle mass, and the suture line was rotated proximally to avoid pin pressure later. The medial end of the tube was stitched to the medial skin margin and to the overlying muscle. The free edge of the lateral end of the skin tunnel was sutured to the overlying

FIG. 5

Lateral view of the quadriceps cineplasty and prosthesis.

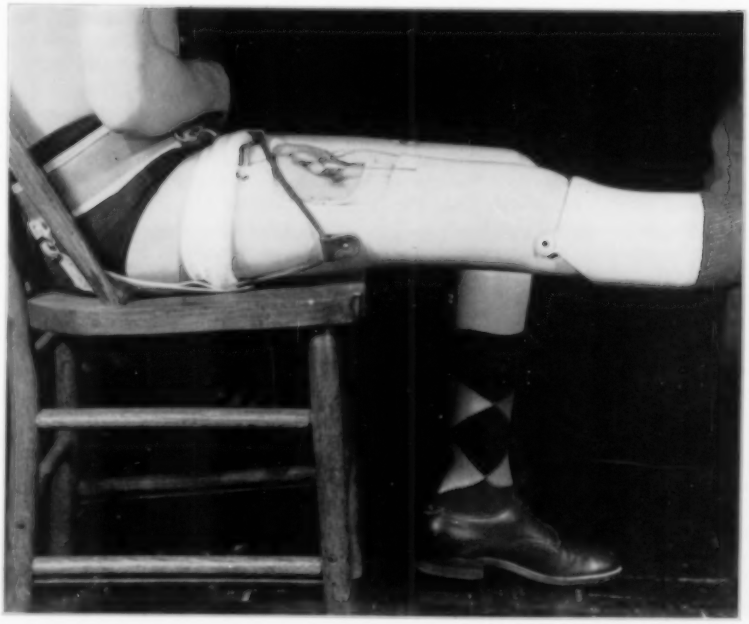

FIG. 6

Lateral view of the cineplasty illustrating complete active extension of the leg and foot.

muscle. This produced "fish-mouth" openings. The surface denuded of skin was then covered with a split-thickness skin graft removed from the abdomen.

The operative sites healed satisfactorily without complication in approximately four weeks. The muscle tunnel was then fitted with an oxbow-shaped acrylic pin three-fourths of an inch in diameter. The muscle was exercised by attaching the pin to an exerciser. On April 10, 1953, the muscle had an excursion of one and one-half inches with a maximum tension of 100 pounds in the pre-resting phase and a usable excursion of one and one-quarter inches. The patient gradually built up a tension of 150 pounds.

The socket of the prosthesis for the end-bearing stump was modified; an opening was cut in the anterior portion of the socket to expose the quadriceps tunnel and the portion of the socket above the tunnel was closed by a lacer. Control cables fastened to the ends of the acrylic pin in the quadriceps tunnel were carried through sleeves in the socket to an eccentric cam on the bolt of the knee joint. The cam was adjusted so that the one and one-quarter inch excursion of the quadriceps tunnel would cause the knee of the prosthesis to straighten from 90 degrees to complete extension, the variation in power in its arc of motion being such that in the final phase of extension there was the greater leverage power (Figs. 1 through 5).

When the patient was discharged from the Hospital in July 1953, he was able to walk with the use of a cane and reported that he had achieved an increased security of stance.

The follow-up examination made in July 1954 revealed that he had used the prosthesis almost daily for periods of eight to twelve hours. He had chosen an ice cream vendor's vocation, which required much standing and walking. He was able to climb stairs, using the cinetized quadriceps muscle to extend and lock the knee joint of the prosthesis. He claimed that he could operate the brake and accelerator of his car with this leg, as it was stable, and could exert pressure in the partially flexed position. The muscle could support 204 pounds, and it had an excursion range of two and one-half inches. Several one-sixteenth-inch cables and acrylic pins had broken during the year's use; this no longer happened when a three-thirty-seconds-inch cable and a tunnel pin of stainless steel were used. He was enthusiastic about his rehabilitation.

## SUMMARY

A quadriceps cineplastic tunnel was provided for the end-bearing stump of a patient with bilateral above-the-knee amputations. The tunnel had sufficient excursion and strength to actively extend the leg section of a simple end-bearing prosthesis and to produce some stability and control in the artificial knee joint.

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# The Naviculo-Capitate Fracture Syndrome

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A fracture syndrome, referred to in this paper as the "naviculo-capitate fracture syndrome", has twice been encountered by the author: once in 1950, in a patient reported as having a fracture of the capitate[1], and once recently in a patient seen at the United States Army Hospital at Fort Bragg. In both instances the lesion posed a problem in diagnosis and treatment. The identical pattern displayed in these cases with regard to mechanism, roentgenographic appearance, and pathological findings warrants the making of a greater effort in the future to recognize this fracture syndrome, which has not previously been emphasized in the literature.

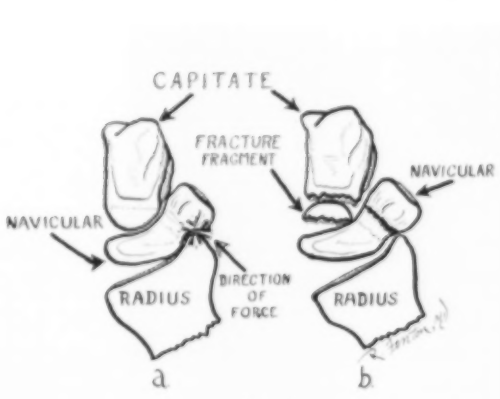


FIG. 1

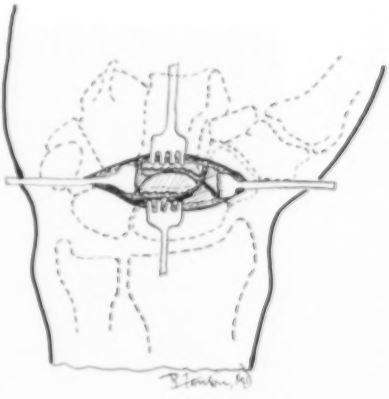

FIG. 2

Fig. 1: Mechanism of the naviculo-capitate fracture.
Fig. 2: Appearance of the fracture at the time of surgery. A transverse incision has been made.

## ANATOMY AND PATHOLOGY

The capitate bone is not normally subject to fracture, for it lies in a central position in the carpus and is surrounded and reinforced by the other carpal bones. Furthermore, it is roughly the shape of a cube and is structurally a sturdy bone. In sharp contrast, the navicular is situated on the outside of the carpal bones, on the radial side, and is an oblong, irregularly shaped bone with a narrow vulnerable waist.

During a fall, when the hand is outstretched in a position of dorsiflexion and radial deviation, the pointed radial styloid process (the chisel) impinges on the navicular laterally at its waist and the sturdy capitate (the anvil) supports the navicular medially. When the force of a blow from a fall on the outstretched hand is only moderately strong, the navicular alone will be fractured (usually through the waist). When the blow is particularly sharp and violent, however, and when the hand is in a particularly vulnerable position, the capitate will also be fractured. In the latter case, the force from the blow will be transmitted from the radial styloid process, through the navicular, onto the end of the capitate (Fig. 1). The roentgenograms made in both the author's cases show that the fracture line in each bone is a direct continuation of the fracture line in the other bone, the lines in the two bones running together smoothly and without interruption.

In the capitate, as in the navicular, the blood supply for the entire bone enters through the distal surface, the proximal surface being completely articular. Thus, when

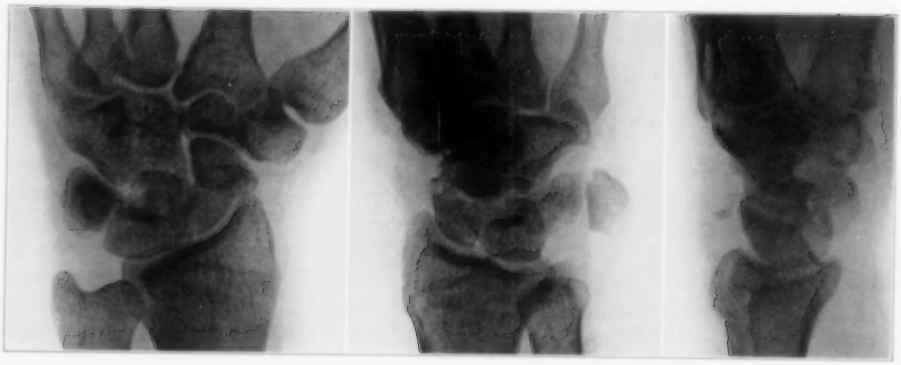

FIG. 3

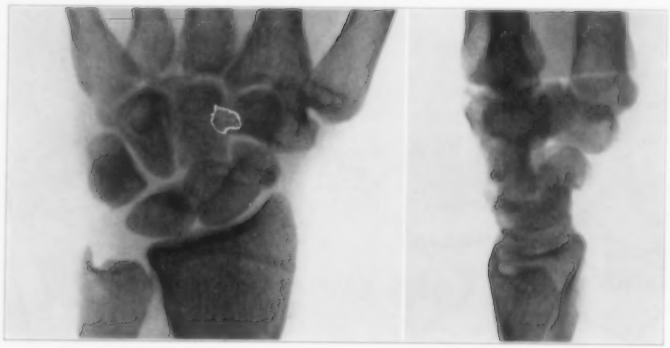

FIG. 4-A

the naviculo-capitate fracture occurs, separating the proximal end of the capitate from the distal end, it leaves the former entirely without blood supply. The area which receives the blood supply in the capitate is far greater than the corresponding area in the navicular.

The nature and degree of the force which factures the capitate is apparently such that it rotates the proximal fragment 180 degrees (Fig. 2). In both of the author's cases this rotation occurred and the result was that the joint cartilage, which covers a large portion of the proximal fragment, was found in contact with the fractured surface of the distal fragment. At first the presence of this deformity added greatly to the confusion of the picture presented in the roentgenograms. Once a diagnosis of naviculo-capitate fracture syndrome had been made, however, the picture became clear.

## CASE REPORTS

CASE 1. On December 11, 1954, a white soldier, thirty-one years of age, fell down a flight of stairs, landing on his outstretched left hand. Five hours later he presented himself in the emergency room complaining of pain in his left wrist and right hip. An examination revealed bruises on the right side of the forehead and contusions on the right hip. It also showed that the left wrist was swollen and that there was crepitation on motion. No gross deformity of bone was noted. Roentgenograms were then made (Fig. 3). These roentgenograms demonstrated a fracture through the waist of the navicular and another through the proximal end of the capitate. They also showed that the proximal fragment of the capitate had been rotated 180 degrees. A third fracture was found in the distal end of the radius; this fracture was linear, and there was no displacement of the fragments.

On December 14, under tourniquet control, a transverse incision was made over the mid-dorsum of the wrist at the level of the mid-carpal joint. The soft tissues were split longitudinally, the extensor tendons were retracted, and the joint capsule was opened transversely. When the edges of the split in the capsule had been

FIG. 4-B

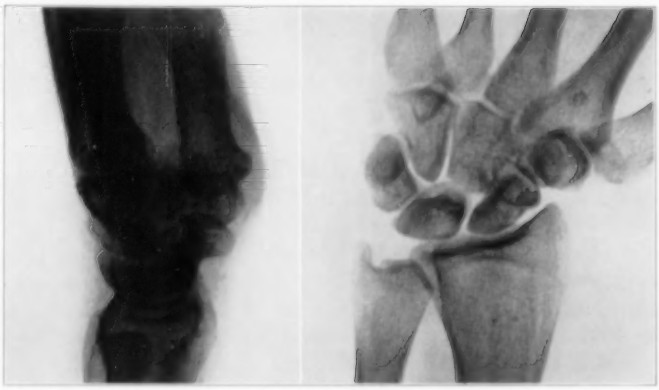

FIG. 4-C

retracted, it was found that the joint was filled with the products of hemorrhage and that the proximal fragment of the capitate was lying free, without any soft-tissue attachments, having been rotated 180 degrees. The bone fragment was lifted from the wound, and the joint was irrigated. The fracture surface of the distal portion of the capitate was smoothed with a rongeur. The fracture of the navicular could be seen, and it was apparent that the fragments were in good position. The wound was then closed, a continuous, subcuticular No. 36 wire being used. A compression bandage was applied and the tourniquet was released. On the first and second days after the operation, stellate ganglion blocks were given to minimize swelling. On the tenth day the suture was removed; the wound had healed. A plaster-of-Paris bandage was then applied to the arm from the crease in the palm to below the elbow, the proximal phalanx of the thumb being included. This bandage was continued until early in June, by which time the fragments of the fractured navicular had united. On July 20th the patient returned to full duty. There was a full range of motion in his wrist at this time, and he experienced no pain except for slight discomfort after strenuous activity.

CASE 2. A Puerto Rican male, eighteen years old, was first examined on September 25, 1950, one month after having been injured. He had fallen backwards in the street, landing on his outstretched left hand. He had had immediate pain and disability in the injured wrist but had sought no treatment until over four weeks later, when the pain had become very disturbing.

An examination on admission revealed a swollen left wrist which he held in a neutral position. There was diffuse tenderness over the dorsum of the wrist, especially over the anatomical snuff-box, and all motions were markedly restricted and very painful.

Roentgenograms made at this time (Figs. 4-A and 4-B) revealed the presence of a fracture through the distal third of the navicular. They also revealed a hemispherical fragment which appeared at first to belong to the navicular, being just ulnarward to the proximal end of this bone. A closer inspection of the roentgenograms revealed, however, that this fragment was actually the head of the capitate. The capitate, it appeared,

had also been fractured, and its head had been separated from the rest of the bone and had been rotated 180 degrees.

Shortly after the patient had been admitted, the joint was explored. The head of the capitate had been rotated as described and was lying in the joint, attached to the ligamentous structures by a single narrow fibrous strand. This fragment was removed. The alignment of the fragments of the fractured navicular was found to be excellent, but there was no evidence of union. The wound was closed and a plaster-of-Paris bandage was applied to the arm from the palmar crease to below the elbow, the proximal phalanx of the thumb again being included. This bandage was continued for sixteen weeks, after which time the fracture had healed and mobilization could be begun. When last seen in the spring of 1953, the patient had a painless wrist; there was a loss of about 15 degrees of dorsiflexion and 10 degrees of volar flexion (Fig. 4-C).

## TREATMENT

The pathological nature of this fracture syndrome determines its treatment. Because the fragment of the capitate is avascular and because it has been rotated 180 degrees, its excision is necessary. This excision may be performed easily, however, for the fragment usually lies free in the joint with no ligamentous attachments. A transverse, dorsal incision, made at the mid-carpal level, should be used in this operation, and postoperatively rigid and prolonged immobilization should be maintained. This immobilization is necessitated by the presence of the navicular fracture; the capitate fracture alone would not require immobilization. When union of the navicular fragments has been obtained, the patient may be given whirlpool and active exercise. If union should not be obtained, however, the lesion should be treated in the same manner that any isolated ununited fracture of the navicular is treated.

If it is desired, the lag-screw method of McLaughlin may be used, the screw being inserted through a separate incision at the time of the operation. This method, which the author has never used, obviates immobilization.

G. Blundell Jones recently reported a case which is similar to those presented here. He treated his patient by immobilization without surgery, and the fracture healed in the position of injury, namely, with the proximal end of the capitate rotated 180 degrees. The functional result was excellent, the range of motion obtained in the wrist being three-quarters that of the normal. It was Dr. Jones' opinion that the injury was a transnavicular, transcapitate, perilunate fracture-dislocation of the carpus which underwent spontaneous reduction.

## CONCLUSION

The author urges that in the future all wrist fractures be carefully appraised with the naviculo-capitate fracture syndrome in mind. It is felt that an appreciable number of these fracture syndromes go unrecognized and that they may represent a small percentage of the cases of fractures of the wrist in which clinically poor results have been obtained.

## REFERENCES

1. Fenton, R. L., and Rosen, H.: Fracture of the Capitate Bone—Report of Two Cases. Bull. Hosp. Joint Dis., **11:** 134–139, 1950.
2. Jones, G. B.: An Unusual Fracture-Dislocation of the Carpus. J. Bone and Joint Surg., **37-B:** 146–147, Feb. 1955.

# A Universal-Length Dual-Pin Plate for Transfixion of the Upper Portion of the Femur

BY J. VERNON LUCK, M.D., LOS ANGELES, CALIFORNIA

The dual-pin plate described in this report has the following features: (1) universal length of the pin portion; (2) lateral fixation without the threat of causing the pin to protrude into the joint and the acetabulum; (3) automatic shortening of the dual pin with either bone absorption or engagement of the fracture fragments.

## DESIGN

The fixed pin of the appliance is combined with a lateral plate and can have one of a variety of cross-section designs—V-shaped, curved, or three-flanged. Because of the simplicity of construction, the V-shaped pin, which is similar to the Neufeld pin, was the one used during the testing period. On the fixed pin slides a second pin which gives the pin assembly its universal length and its ability to shorten if, at the fracture cleft, there is bone absorption or engagement of the fracture fragments.

In an effort to devise a universal-length pin, an appliance was designed in 1942 in which the lateral plate portion was continued through the lateral femoral cortex inside the intertrochanteric area for two inches in a V-shaped, curled-flange construction, made to receive a long, straight, V-shaped, or three-flanged pin which was inserted the desired length, and cut off. Holes, which were placed at every centimeter, were used to facilitate the cutting of these pins. The basic construction is similar to that used in the Badgely and the Pugh upper femoral appliances. The pin-plate described in this report, considerably altered from the original construction, has proved to have advantages over the original design, principally in the ease of insertion, the better fixation afforded, and the simplicity of construction. The pin portion cannot migrate laterally and protrude into the lateral soft tissue. Stress analyses have been made which indicate the pin is of strong construction. There have been no instances, thus far, in which the pin either bent or broke.

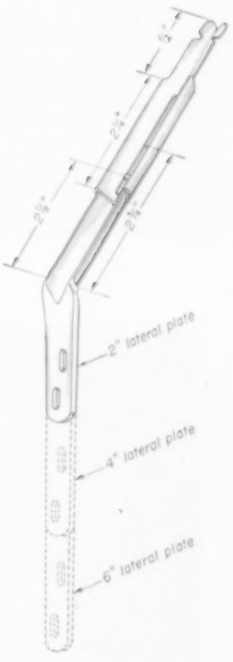


FIG. 1

## TECHNIQUE OF INSERTION AND EXTRACTION

The universal-length dual-pin plate is inserted in the same manner as single pin plates (Neufeld, Austin Moore, Blount, Jewett, or Thornton). Only the lateral femoral cortex is drilled for the insertion of the appliance. The sliding pin seats proximally, stopping at the junction with the lateral plate (Fig. 4-A). After the dual pins of the appliance have been driven in until the lateral plate is flush with the femoral shaft, the plate is held in position by means of a Lowman clamp. With a V-shaped driver (Fig. 5), the sliding pin is driven inward over the fixed pin until the desired depth in the femoral head is reached (Fig. 4-B). When this has been achieved, the Lowman clamp is removed, and screws are inserted to fix the lateral plate to the femur. Extraction was formerly carried out separately for the two pins. The fixed pin was withdrawn by an extractor fixed to the lateral plate at the

FIG. 2-A

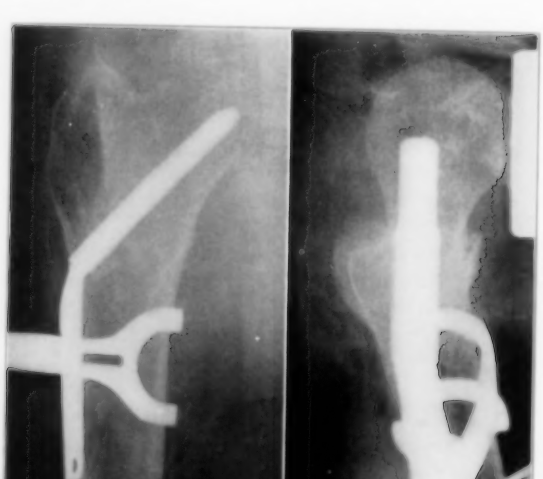

FIG. 2-B

Fig. 2-A: Comminuted intertrochanteric fracture of the femur. Roentgenogram was made on February 4, 1954.

Fig. 2-B: Fracture was reduced and dual-pin assembly was inserted. Roentgenograms were made on February 5, 1954.

FIG. 2-C

Sliding pin was driven deep into the femoral head. Roentgenograms were made on February 5, 1954.

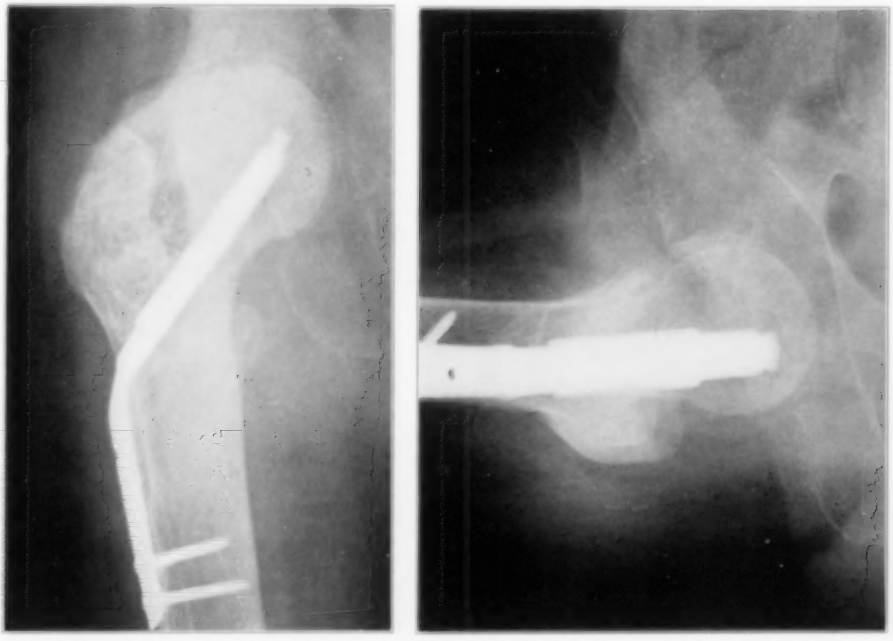

FIG. 2-D

The dual pins automatically telescoped together approximately one-half inch to adapt themselves to engagement of the fracture fragments. Roentgenograms were made on September 10, 1954.

pin-plate junction and the sliding pin was then extracted by a hook that was hooked into a $\frac{3}{32}$-inch hole in the proximal end of the pin. This proved to be difficult at times; therefore, a narrow slot in the proximal half of the sliding pin was made, and in the fixed pin, a small, centered, steel peg was set inside the slot. As the fixed pin is extracted, the center peg comes to the end of the slot and then serves to extract the sliding pin.

## INDICATIONS

Fractures of the femoral neck, of the intertrochanteric region, and of the subtrochanteric region can be well transfixed with the universal-length dual-pin plate. A subtrochanteric or intertrochanteric osteotomy can be transfixed with or without altering the angulation of the lateral plate. One of the problems in using a single pin plate for the fixation of upper femoral fractures has been the danger that the pin would protrude into the hip joint and acetabulum. This complication is prevented by the dual pin design. For subtrochanteric osteotomies or a subtrochanteric fracture, a longer lateral plate is used.

Perhaps the most useful application of the dual pin is in fractures of the neck of the femur. Conventional straight pins, screws, and bolts frequently do not have the capacity for giving adequate lateral fixation even with low insertion. This is particularly true, in numerous instances, when osteoporosis is advanced. In the area between the thin lateral cortex and the femoral head, there is relatively little bone adequate for fixation. All too frequently, movement develops at the fracture site with "jiggling" of the pin, leading to absorption of the femoral neck, non-union, and lateral migration of the pin. Inadequate fixation appears to be the most frequent cause of non-union in fractures of the femoral neck. The dual pin here described gives secure lateral anchorage and at the same time permits deep insertion into the femoral head, the needed fixation being gained without subsequent protrusion into the hip joint and acetabulum. The universal length gives as-

FIG. 3-A

FIG. 3-B

FIG. 3-C

FIG. 3-D

Fig. 3-A: Displaced subcapital fracture of the neck of the femur. Roentgenogram was made on June 30, 1954.

Fig. 3-B: Fracture was reduced and dual-pin assembly was inserted. Roentgenogram was made on July 1, 1954.

Fig. 3-C: The sliding pin was driven deep into the femoral head. Roentgenogram was made on July 1, 1954.

Fig. 3-D: The healing process at the fracture site was associated with slight shortening, adapted to by the sliding together of the dual pins. Note, however, that the depth of penetration into the femoral head has changed slightly. Roentgenogram made on October 5, 1954.

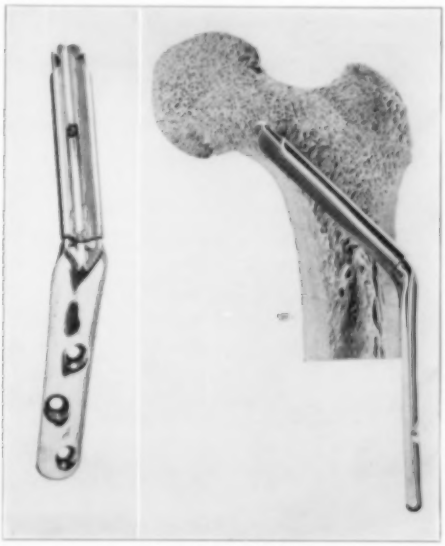

FIG. 4-A

FIG. 4-B

Fig. 4-A: The two pins of the appliance are telescoped together.

Fig. 4-B: The sliding pin has been advanced on the fixed pin. The pin deviates into the upper one-half of the femoral head. A better position is the center of the head, or slightly below the mid-point.

surance that the pin will be precisely the correct length and the lateral plate gives protection against both lateral migration of the pin and failure of fixation.

## RESULTS

During the past three years, this dual pin has been employed in fourteen selected cases for the transfixion of fractures of the upper portion of the femur. The cases were selected to constitute, within a small test series, the various types of fractures encountered in the upper portion of the femur in which pin fixation is the treatment of choice. A preliminary experimental series has been studied in order to determine the degree of fixation achieved, the capacity of the appliance to adapt itself to telescoping of fracture fragments, and, lastly, the dimensions that would give the dual pins universal length.

In two instances, the pin has migrated deeper into the femoral head during the period of fracture healing and in one of these cases there was penetration into the hip joint, necessitating removal of the pin at the completion of healing of the femoral-neck fracture. In both of these cases, the femur was small, and the fixed pin of the appliance was too long. The dual pins telescoped together postoperatively, following which further absorption of bone at the fracture site led to migration deeper into the femoral head and, in one instance, into the hip joint. Since these experiences, care has been taken not to make the fixed pin so long. Its length has varied in different pins of the series from three inches to two and a quarter inches.

In all of the cases, with the exception of the two mentioned, the pin has functioned in the manner anticipated and has adapted itself whenever there has been absorption of

FIG. 5

The V-shaped driver as it is applied to drive the sliding pin deep into the femoral head.

bone at the fracture site or engagement of the fragments. There have been no instances of failure of union in this series, although in three instances union was delayed somewhat beyond the expected time of healing. In one instance, nine months were required for union to take place.

In only one instance has there been a definite avascular necrosis of the femoral head. However, more cases of this complication may yet appear. No postoperative infections have been encountered. One death occurred three weeks postoperatively from a cerebral accident and a second death, at the end of three months, from uraemia. The length of the follow-up has been more than one year in all instances in this series; in two cases the follow-up has been three years and in eleven cases the follow-up has been between one and two years.

The age distribution extended from fifty-eight to ninety. Six of the patients were females, and eight were males.

Three of the fractures were intertrochanteric and eleven were various patterns of fracture of the femoral neck. Of the eleven femoral-neck fractures, graded by the Pauwels' method, two were *Grade I*, five were *Grade II*, and four were *Grade III*.[1]

1. PAUWELS, F.: Der Schenkelsbruch. Ein mechanisches Problem. Stuttgart, Ferdinand Enke, 1935.

# A Modified Hand Drill

BY ROBERT C. BECHTOL, M.D., SANTA ROSA, CALIFORNIA

A standard surgical drill with enclosed gearing has been modified for easier use in close quarters. Its chief use is in conjunction with the standard 7/64-inch bone screw, such as is used in internal fixation of fractures. The lack of a drill chuck near the drill point allows the point to be placed in small incisions or close to fixation instruments and prevents tissue trauma caused by a whirling chuck. Nothing moves in the wound except the drill point.

The nose piece of the drill can be removed, and the chuck can be placed on the front of the drill in the conventional manner. This allows the use of larger-diameter drill points. With the nose piece attached, standard 7/64-inch drill points, nine inches long, are used.

To modify the drill, the handle of the original instrument was removed, as shown in Figure 1, and was welded to the body of the drill, as shown in Figures 2 and 3. Figure 3 shows how the handle is placed at an angle to the body of the drill. A duralumin nose piece was made to thread into the front of the drill after cutting suitable inside threads in the shaft housing. The original front bronze bushing for the shaft was slid back far enough

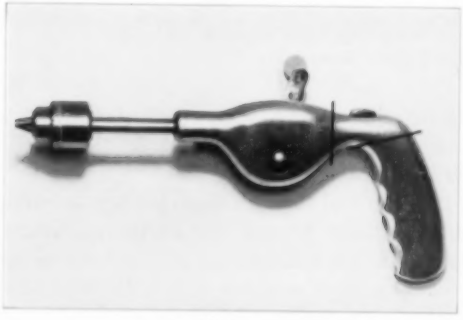

FIG. 1

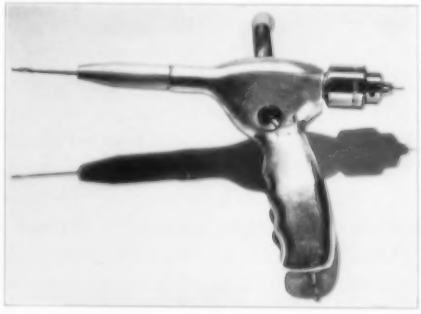

FIG. 2

Fig. 1: The original drill, showing location of saw cuts for removal of handle.
Fig. 2: Handle removed from back of original drill and welded to body of the drill.

FIG. 3

FIG. 4

Fig. 3: Handle placed at a 35-degree angle to the body of the drill.
Fig. 4: Drill set up for use in conventional manner.

to allow the cutting of these threads. The front of the nose piece was bored slightly larger than the 7/64-inch drill which is to be used. An adjustable collett for the front of the nose piece could be used for different drill sizes, but this has been found to be unnecessary since this drill is used almost exclusively for standard bone screws which require a 7/64-inch drill point. Figure 4 shows the drill set up in the conventional manner without the nose piece and with the chuck at the front of the drill.

# A Broaching Smith-Petersen Nail Starter

BY COLONEL STERLING T. RITCHEY, *Medical Corps, United States Army,*
AND MARK G. LAZANSKY, M.D., BRONX, NEW YORK

*From the Orthopaedic Service, Walter Reed Army Hospital, Washington, D. C., and the Bronx Municipal Hospital Center, Bronx, New York*

The appearance of stellate cortical fracture lines at the time of starting a Smith-Petersen nail in the lateral femoral cortex is an unwelcome operative complication, as nail stability is obviously lost until the fractures have healed about the nail.

Many methods for starting the Smith-Petersen nail through the often brittle lateral cortex of the femur have been devised, but none have proved completely satisfactory. Three-flange nail starters with sharp end-cutters have not eliminated this bothersome operative complication. Multiple osteotome cuts, with or without drill holes, are time-

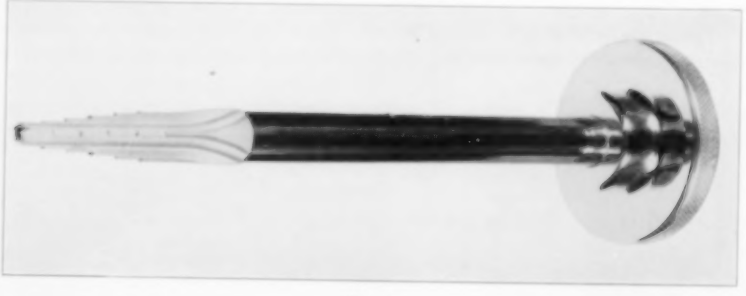

FIG. 1

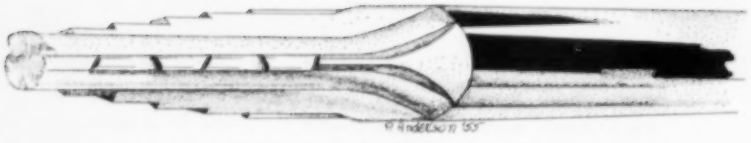

FIG. 2

consuming and difficult to align correctly. The use of a large burr hole at the site of the nail entrance sacrifices the intended stability of the nail in the lateral cortex which is necessary for secure fixation. The simple driving of the nail over a guide wire frequently results in cortical stellate fractures, and, when the nail is obliquely placed, the "creeping up" of the nail with bending of the guide wire is difficult to control.

To reduce these complications the drill broach principle was applied in designing the nail starter described here. The starter may be constructed from a standard Smith-Petersen nail, the ordinary driver and extractor being used. However, an improved design constructed of hardened steel, manufactured in one piece, with provision for a "tapping-out" flange, is now constructed by a commercial instrument manufacturer (Fig. 1). Details of the broach construction are illustrated in Figure 2.

After satisfactory placement of a standard 3/32-inch calibrated guide wire, the cannulated starter is passed over the wire to the cortex, turned by hand until the end-cutting teeth of the center hub have penetrated the cortex, care being taken not to change the angle of the guide wire by bending. The starter flanges are turned to the desired position and are advanced by gentle mallet taps through the cortex until the last broaching tooth has passed. The starter is removed by gentle "tapping-out" on the flange handle extremity. The correct length Smith-Petersen nail fits through the broached pattern with only snug pressure and with no tendency to drift upward or to split the cortex. Cortical fractures have not occurred in cases in which this starter has been used, and nail-fixation stability in the cortex has been improved. "Creeping up" of the nail and bending of the guide wire at the time of starting has also been eliminated, nail flange damage or bending does not occur, and operative time has been shortened.

# Proceedings

## THE AMERICAN ACADEMY OF ORTHOPAEDIC SURGEONS

The Twenty-third Annual Meeting of The American Academy of Orthopaedic Surgeons was held at the Palmer House, Chicago, January 28, 29, 30, 31 and February 1, 2, 1956. Dr. Walter P. Blount presided.

For six days it was a full house with a full schedule. For many hard-working members of Boards and Committees, it was an even longer session. The American Board of Orthopaedic Surgery conducted examinations of candidates on the three days preceding the opening of the meeting. Friday was a full day for the American Society for Surgery of the Hand from early breakfast until "dinner at eight". Numerous other committees and societies met on Friday and Saturday, including the Board of Associate Editors of *The Journal of Bone and Joint Surgery* whose annual meeting and dinner took place on Saturday. Starting with

FIG. 1

At the President's table during the annual banquet.

Seated left to right: Mrs. Claude Lambert, E. J. Berkheiser, Mrs. Clinton Compere, H. Osmond-Clarke of London, Mrs. Walter Blount, Claude N. Lambert, Mrs. Osmond-Clarke, President Blount, and Mrs. Berkheiser. Standing are D. M. Bosworth, A. Della Pietra, and N. Pollack.

the morning of January 29, 1956, a distinguished faculty of one hundred and six members conducted ninety-four Instructional Courses, including, for the first time, three courses presented through the medium of color television. In the seven SRO sessions of the Scientific Program members and guests heard the presentation and discussion of twenty-eight papers. Nineteen other presentations were made in the course of the Audio-Visual Program. Between sessions the many scientific, gadget, and technical exhibits received well-merited study. The end of the day found everyone ready for the refreshment and relaxation of the evenings. Through the week many alumni associations met at luncheons or dinners. An energetic entertainment committee under the guidance of Mrs. Claude N. Lambert made the attending ladies glad they had come.

There was a strong international flavor to the assemblage, including a large representation from Latin-America. A highlight in the memories of those who attended will be the bamboo canes that blossomed in the lobbies after Dr. Blount's Presidential Address. (See next page)

On the morning of the last day of the meeting the new President, Dr. William T. Green, was inducted into office and was escorted to the chair.

The Annual Banquet took place Wednesday, February 1. In an innovation of its own *The Journal* is this year presenting visually, on this and the following pages, the brilliance of this assemblage.

*(Continued on page 709)*

# Don't Throw Away the Cane *

BY WALTER P. BLOUNT, M.D., MILWAUKEE, WISCONSIN

As the causes of premature death are conquered one by one, man is given a longer life in which to grow old gracefully. In the twilight years that his forefathers rarely knew, he needs help in seeing, hearing, chewing, and walking. Gradually we are coming to look upon eye glasses, hearing devices, and dentures as welcome aids to gracious living rather than as the stigmata of senility. They should be accepted eagerly as components of a richer life. The cane, too, should be restored to favor as a means of preventing fatigue and a halting gait, rather than maligned as a sign of deterioration.

The use of the cane in order to prevent strain upon an ailing hip or knee is not generally accepted. In the patient's mind there is a nice distinction between the permissible use of a stick postoperatively and the adoption of this humble support for no other reason than the relief of a slight physical infirmity. A fat lady may waddle like a duck when she laboriously walks a few steps, but she resents the suggestion that she carry a cane. She would look much better with a stick than with the limp; and with support she could walk enough to get some exercise. More walking would help with weight reduction. But no! she is not ready for a cane *yet!* The patient with residual disability after poliomyelitis and with a fatiguing, unsightly lurch needs a cane. Early degenerative hip disease may require no treatment other than weight reduction and a stick in the opposite hand; however it takes an impressive orthopaedic surgeon to sell the idea.

Pride is not always the major obstacle. There is no place for the stick in modern society. Man rarely walks. He rides in a car or a bus. The busses are crowded, and there is scarcely room in the modern car for the occupants to sit upright, without adding a stick. Your grandfather proudly rested his hands on the knob of a cane as he was driven behind good horses. He stepped out briskly with his stick at the end of the ride. Now man must limp between busses without benefit of a cane.

How our attitude toward the cane has changed! Earliest man demonstrated his superiority to the beasts by carrying a stick in order to beat them off. The staff became a spear. The soldier leaned on the shaft when tired. The shepherd enjoyed the support of his crook.

The artist and the cartoonist have given us the history of the cane. In the Egyptian tombs of the Sixth Dynasty (2830 B. C.) the crude staff was illustrated. The stick gradually became a popular accessory that served many purposes. The nobleman struck at stray dogs and cudgeled his slaves if they did not bow low enough. The cane became a symbol of power and aristocracy. Officialdom appeared with a mace or crosier. A jaunty stick was carried by men and women alike at the race track and at the watering place.

Following the publication in 1827 of the delightful medical biography, *The Gold-Headed Cane*, no well established doctor appeared in public without this symbol of his profession. The smooth polished stick was provided at the top with a hollow gold knob or crossbar containing aromatic vinegar. The man of science held this to his nose so that the fumes might protect him from the exhalations of the sick person. The cane descended to the doctor from Hermes or Mercurius, and, until our generation, it was as much a symbol of the healing art as was the caduceus. Now the doctor, as well as the patient, would rather suffer great discomfort than the indignity of carrying a cane.

The advertisements of fifty years ago rarely depicted a stylish person without a cane.

* Presidential Address read at the Annual Meeting of The American Academy of Orthopaedic Surgeons, Chicago, Illinois, January 30, 1956.

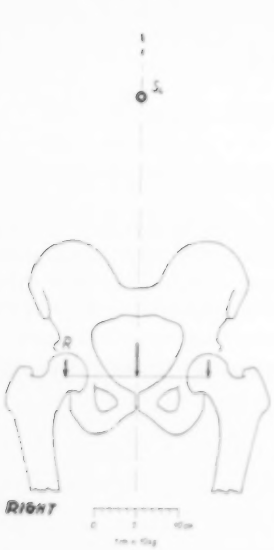


FIG. 1

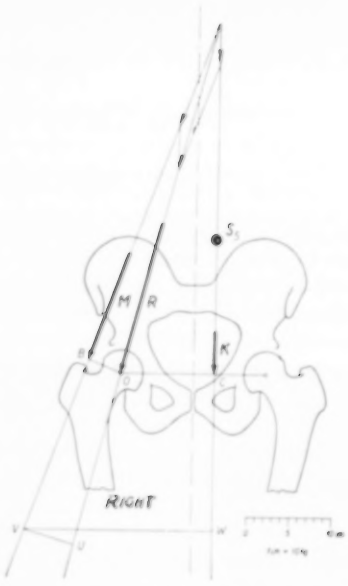


FIG. 2

Fig. 1: When the patient stands, the weight of the body above the lower extremities, $S1$, rests equally on the two normal hip joints. The static force on each hip, indicated by a short arrow, $R$, is one-half of the total superimposed weight. (From Pauwels[6]. Reproduced by permission of Ferdinand Enke Verlag.)

Fig. 2: (See also legend for Fig. 3.) Without moving the trunk or the pelvis the subject in Fig. 1 has lifted his left lower extremity by flexing the hip and knee as though the left lower extremity were in the swing phase of walking. The weight of the left lower extremity is added to that of the torso, head, and arms, increasing the total weight and moving the center of gravity of the body to the left to $S5$. The body weight that must be borne by the stationary right lower extremity is represented by the heavy line $K$. The abductors of the stationary right hip must pull downward on the right side of the pelvis at $B$ (vector $M$) strongly enough to support and to maintain in equilibrium the weight $K$. The force downward on the fulcrum at $O$, the hip, is the sum of the vectors, $M$ and $K$, expressed as $R$. The amounts of the downward pull by the abductors at $B$ and the downward force at $C$ are directly related to the relative length of the levers $B$ to $O$ and $O$ to $C$. If $B$ to $O$ is one-third of $O$ to $C$, the downward pull of the abductor muscles at $B$, expressed as $M$, must be three times the downward force at $C$, which is $K$, if the forces are to balance. The total pressure on the top of the femur, $R$, is the sum of $M$ and $K$, or four times $K$. (From Pauwels.[6] Reproduced by permission of Ferdinand Enke Verlag.)

A man was not fully dressed without his stick. Today only a few of the famous characters in advertisements still carry canes.

At present, attractive walking sticks can be purchased at only a very few smart shops. Beautiful canes are collector's items or dust catchers in storage attics. A patient rarely displays the ornamented cane which he inherited from some distinguished ancestor. The modern varnished stick with a rubber tip is usually obtained from a brace shop or drug store. This utilitarian model is not esteemed as an accessory.

To become popular again, the stick must be both beautiful and efficient. It should hang from the forearm in order to free the hand, but it should remain within easy grasp. Canes might be sold like cars on the basis of novelty features. Hidden swords are no longer permissible, but many ancient cane accessories could be revived. Flashlights, bottles, umbrellas, and even built-in radios would be useful. Beautiful plastics could be combined with the newer alloys in order to increase the sales appeal.

Following a serious injury or an operation on a hip, most patients of sixty or seventy years should continue the use of a support indefinitely in order to protect the injured part from further insult. They would gladly do so were it not for vanity and for public opinion. The injured workman is not permitted to return to any job as long as he is using a support,

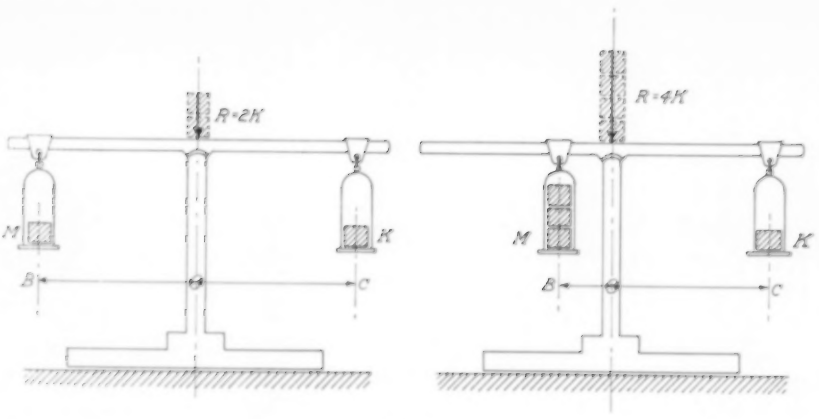


FIG. 3

Fig. 3: The forces operating at the hip are well illustrated by the simple balance. In this pair of drawings, as well as in Fig. 4 and in the diagrams of the hip, it is agreed that, for absolute accuracy in establishing a complete system according to the laws of physics, the forces represented by the vector $R$ should have the arrow pointing upward to represent the upward thrust of the femur. Throughout these illustrations, this arrow has been reversed to point downward in accordance with the orthopaedic concept of downward pressure on the hip, rather than upward pressure of the femur against the pelvis.

Consider that the column which supports this balance has been provided with some kind of a device for measuring the total weight which is resting on the fulcrum. In this series of drawings, the force designated by the letter $M$, represents the force exerted by muscles to counterbalance the weight $K$. The total weight upon the column of this balance must equal the weights at $M$ and $K$. For the sake of simplicity, the weight of the balance beam and its accessory equipment will be disregarded. On the left, the superimposed weight $R$, which is equal to two $K$, is divided equally at $M$ and $K$ — the perfectly balanced condition when the normal human body is standing erect.

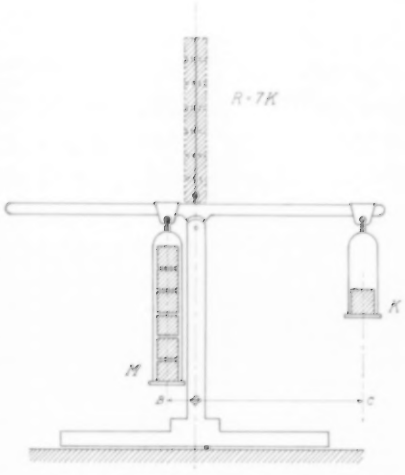


FIG. 4

In the same type of diagram on the right, the approximate hypothetical relationships are represented when one lever is shortened as in our last hip schema (Fig. 2). The lever arm, $B$ to $O$, is one-third the length of the lever arm $O$ to $C$. In order to balance the weight $K$, it is now necessary for the weight $M$ to be three times the weight $K$ in order to maintain equilibrium. This means that the center column supporting the balance beam must now withstand pressure four times that of $K$. (Redrawn from Pauwels [7])

Fig. 4: (See also legend for Fig. 3.) The lever $B$ to $O$ is one-sixth of the length of the lever $O$ to $C$. It will now take six times the weight $K$ applied at $M$ in order to balance the weight $K$. The weight $R$, supported by the column, will be the sum of $M$ and $K$, or seven times $K$. This represents diagrammatically what happens when the hip is in marked valgus position. (Redrawn from Pauwels [7])

so he abandons his cane while he still needs it. We must counteract this prejudice. Let us start a movement to *employ the cane carriers*. We must educate the doctors, patients, employers, and the general public to turn back to the old order and to look upon the stick as a good friend. Here are some scientific reasons why it is needed.

To review the mechanics of the hip, let us start with a diagram (Fig. 1) taken from the much quoted, but little read, monograph of Pauwels, published in German in 1935.[6] It represents the weight of the body above the lower extremities resting equally on the two normal hip joints. The static force on each hip is one-half of the total superimposed

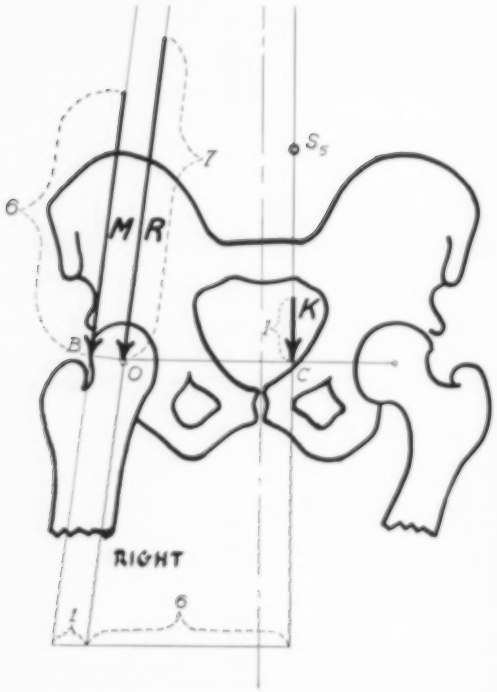


FIG. 5

FIG. 6

Fig. 5: The valgus hip is represented schematically on the right. The pull of the abductors at $B$ is at the end of an abnormally short lever arm, $B$ to $O$, which is only one-sixth of $O$ to $C$. The pull downward at $B$ must be six times $K$ in order to maintain equilibrium when the left foot is raised. The total pressure on the stationary right hip is seven times $K$.

Fig. 6: When there is a valgus deformity of the right hip, the patient actually reduces the pressure on the head of the femur by listing the trunk to the right as she steps on the right foot. This displaces the center of gravity to the right so as to require much less pull of the abductor muscles on the right, and consequently much less force on the head of the right femur.

weight, or less than one-third of the total body weight. Muscles are relaxed, and muscle pull is not a factor.

In Figure 2, one must suppose that the same patient (facing the reader with the right side clearly marked) has lifted his left lower extremity by flexing the hip and knee as though the extremity were in the swing phase of walking. He has not moved the trunk or pelvis. The weight of the left lower extremity is added to that of the torso, head, and arms, increasing the total weight and moving the center of gravity of the body to the left. In this hypothetical and simplified schema, the actual force that is exerted upon the head of the right femur comprises not only this superimposed weight, but the total force that is momentarily required to maintain the balance of the pelvis as the left limb is lifted. The abductors of the stationary right hip must pull downward on the right side of the pelvis strongly enough to maintain equilibrium. The force downward on the hip is the sum of the vectors $M$ and $K$. The amounts of the downward pull by the abductors and the downward force of gravity are directly related to the relative length of the levers. If $B$ to $O$ is one-third of $O$ to $C$, it is obvious that the downward pull of the abductor muscles must be three times the force of gravity in order to maintain balance. Then the total pressure on the head of the femur is four times that of the superimposed weight.

With the use of a simple balance (Fig. 3), we can illustrate the mechanics of the forces as they affect the load on the head of the femur. On the left is the perfectly balanced condi-

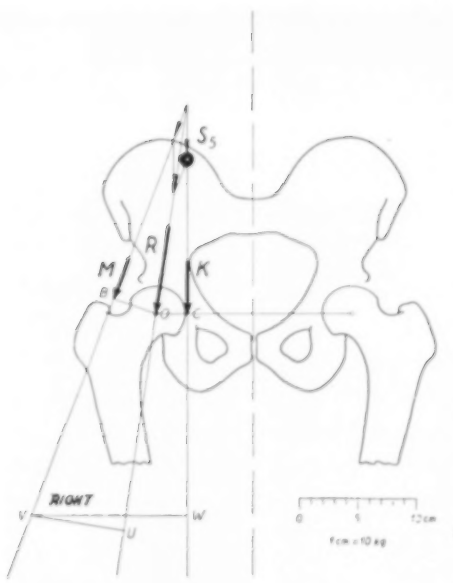


FIG. 7

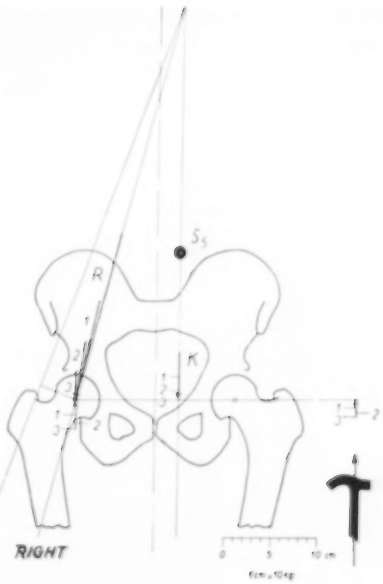


FIG. 8

Fig. 7: In this hip schema, the trunk is listed to the right. The center of gravity, *S5*, is shifted to the right. The lever arm, *O* to *C*, is reduced to less than the lever arm *O* to *B*. There is less pull required of the abductor muscles than the actual body weight so that *M* is less than *K*. The total force, *R*, on the femoral head is only slightly in excess of the superimposed weight. (From Pauwels [6]. Reproduced by permission of Ferdinand Enke Verlag.)

Fig. 8: In the subject studied in the companion Table I, without a stick, the force designated *R* is 385 pounds. A cane used in the left hand supports the body weight, *K*, without requiring as much pull of the abductor muscles. The cane works through a long lever so that a moderate push on the stick greatly relieves the pressure on the hip. Here and in Table I, the various lines labeled 1, 2, and 3 refer to relationships in this average case with varying forces on the cane, while the levers remain constant in length. (From Pauwels [6]. Reproduced by permission of Ferdinand Enke Verlag.)

TABLE I

(See Figure 8)

| | Pounds Pressure on Cane | Pounds Pressure on Femoral Head |
|---|---|---|
| R | 0 | 385 |
| 1 | 20 | 220 |
| 2 | 33 | 113 |
| 3 | 38 | 66 |

tion when the normal human body is standing erect and motionless; the superimposed weight is divided equally between the two hips. In the same type of diagram on the right is represented the approximate hypothetical relationships when one lever is shortened, as in our last hip schema (Fig. 2).

In Figure 4, the relative length of the levers is shown even more unequal in order to represent diagrammatically the situation with the hip in marked valgus position.

The valgus hip is represented in a schematic drawing (Fig. 5). The pull of the abductors is almost twice that if the angle of the femoral neck were normal.

The foregoing is only a hypothetical analysis of forces. In actual life, the patient with a valgus hip limps (Fig. 6), and the force on the right hip is reduced. As weight is borne upon the right lower extremity, the trunk is shifted to the right with an abnormal list so

that the center of gravity is displaced to the right. The result is the characteristic waddle of the fat man or the limp of the man with coxa valga.

Let us see what happens in our hip schema when the patient limps (Fig. 7). With the trunk listing to the right, the center of gravity is shifted to the right. The lever arm *O* to *C*

FIG. 9-A

FIG. 9-B

Fig. 9-A: E. H. Roentgenogram made on February 13, 1950. A trochanteric fracture in a female, age forty-six, had been reduced and is in the valgus position.

Fig. 9-B: Roentgenogram made on April 3, 1950. Secure internal fixation was obtained with a V blade-plate which held the relationship of the head and neck of the femur to the shaft in the valgus position, and two Moore nails which fastened the trochanter to the neck. Bony union was prompt. There was no threat of coxa vara. The patient walked with crutches soon after the operation.

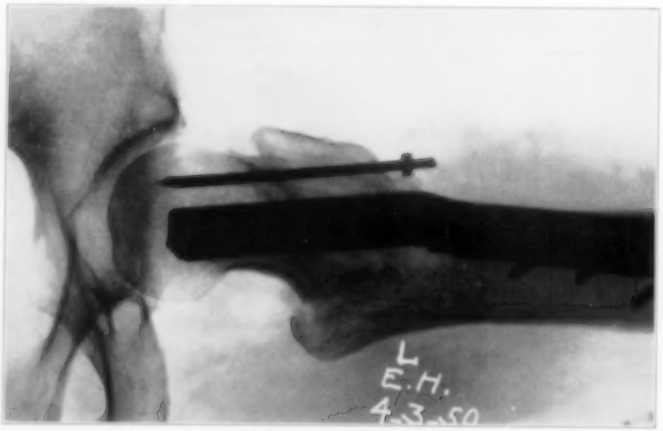


FIG. 9-C

Fig. 9-C: Roentgenogram made on April 3, 1950. The reduction and fixation were satisfactory as seen in the lateral roentgenogram.

FIG. 9-D

Roentgenogram made on December 7, 1955. Avascular necrosis appeared two and one-half years after the fracture, and two years after the patient had abandoned crutches. With the use of crutches for one year, the head was revascularized. Roentgenogram shows the appearance of the hip five years after healing of the fracture. She uses a cane in the right hand. There has been no change in the last two years. Hip motions are only slightly restricted. There is discomfort with changes of weather or overactivity.

is reduced to less than the lever arm $O$ to $B$, and less pull of the abductor muscles is required than that which would be required by the actual body weight. The total force on the femoral head is only slightly in excess of the superimposed weight.

The response to pain in the hip is similar; the result is an antalgic limp. The torso lists to the affected side when weight is borne on this hip in order to reduce the downward force on the femoral head and thus to reduce the pain. In our diagram, if the list is exaggerated enough to shift the weight so that $K$ coincides with $R$, no pull at all is necessary on the abductor muscles. This type of limp is familiar in the patient with completely paralyzed abductor muscles.

Limping, as a means of relieving stress on a hip, may be tolerated in an energetic child, but it is not a desirable gait for an adult. Constant lurching of the torso is fatiguing; it produces excessive strain on the lumbar spine and causes backache. Above all, it is unsightly. The patient does not want to limp! In his sporadic attempts to reduce the lurch, the patient with a normal femoral angle repeatedly increases the pressure on the femoral head up to four times that of the body weight. The man with a valgus femoral neck applies even more force with each step. Rapid deterioration of the hip is inevitable.

The patient of the wise orthopaedic surgeon walks with crutches for six months after a fracture of the neck of the femur. He uses a stick for a longer time — the wiser the doctor, the longer the time. If his medical adviser, his physical therapist, his friends, and his

pride finally drive him to abandon the cane while he still needs one, he limps. He limps in a subconscious effort to reduce the strain on a weakened hip. If there is free motion at the joint, he lists to the same side in order to reduce the pressure on the top of the femoral head, as we have just shown. If there is restricted motion, he cannot shift his body weight but he hurries to remove the weight from the painful hip joint. When his pride makes him reduce the limp to a minimum, the excessive force pressing on the aging hip takes its toll in producing degenerative changes. He should not have thrown away the stick.

As Pauwels has shown so well (Fig. 8), the use of a cane in the left hand reduces the pressure on the right femoral head without the need for limping. The support afforded by the stick greatly lessens the pull required of the abductor muscles in helping to support the body weight. The cane works through a long lever, so that a moderate push on the stick greatly relieves the strain on the hip. The relative forces are shown in Table I. Pauwels estimated that during the stance phase of walking, without the support of a cane, an average person exerts a static force of 385 pounds on the stationary hip. This weight can be reduced to 220 pounds by pushing down on a stick with the opposite hand the equivalent of 20 pounds. The cane is really an efficient mechanical device.

Trochanteric fractures, as well as subcapital fractures, will heal more promptly if reduced in some degree of valgus (Fig. 9-A). So far as it goes, this principle is a good one. With secure internal fixation (Fig. 9-B), a woman, forty-six years old, walked with crutches soon after the operation. Reduction and fixation were satisfactory as seen in the lateral roentgenogram (Fig. 9-C). In the valgus position, bony union was prompt, and there was little danger of coxa vara.

The fallacy in the proposition is this. The position of valgus that ensures rapid healing also reduces the lateral lever in the system of forces that have been discussed and greatly increases the pressure that is brought to bear on the hip as soon as cane or crutches are discarded. A very high percentage of trochanteric fractures that heal in valgus result in avascular necrosis of the femoral head (Fig. 9-D), a rare complication if this fracture heals with the normal amount of varus, that is, with an abductor lever arm of normal length. In the case illustrated, pain and limp appeared several years after the fracture. The patient walked with crutches for one year, and the symptoms disappeared. There was no appreciable change as seen in roentgenograms in two years. An arthroplasty was suggested elsewhere and may be desirable in the future. However, with a cane she has no pain and does not limp. Hip motion is only slightly restricted. She should not throw away the cane!

Consider the seventy-year-old grandmother who is being treated for an impacted fracture of the neck of the femur in valgus position or the seventy-three-year-old lady with arthritis and a vertical fracture of the neck of the femur whose right hip is shown in Figure 10-A. We obtained satisfactory reduction and valgus position by simultaneous osteotomy, closed reduction, and fixation with Moore pins (Fig. 10-B)[2]. If either of these ladies knew of the likelihood of avascular necrosis developing, neither would abandon the support which offers some assurance of preserving the function of the hip; neither would throw away the cane.

At first the patient is timid about abandoning support. An optimistic prognosis from the orthopaedic surgeon encourages him to get rid of his cane. The doctor wants to prove the success of his treatment to the critical world and the patient is inspired to show that he is wholly well again by discarding all support. If the patient is thirty or forty, he should strive for rapid complete recovery; if he is sixty or seventy, he should adopt a cane until several years' observation have proved that the circulation of the femoral head has been wholly re-established. Giving up the stick should not be used as a proof of recovery.

The doctor says to the patient, "You may discontinue the cane as soon as you feel strong enough". No one asks if the femoral head is strong enough; often it is not. The roentgenogram may give evidence of good healing; but doctor, treat the patient, not the picture. The hip may hold out for a year or two and then give up; degenerative changes

FIG. 10-A

FIG. 10-B

Fig. 10-A: I. S. Roentgenogram made October 22, 1943, shows vertical fracture of the neck of the femur in a female, age seventy-three, with generalized atrophic arthritis of moderate grade. Simultaneous osteotomy, closed reduction, and fixation with Moore pins were indicated in order to assure prompt healing and an ultimate good functional result.

Fig. 10-B: Roentgenogram made April 10, 1946, two and one-half years after the roentgenogram seen in Fig. 10-A. The fracture had been reduced and immobilized by two Moore pins. The osteotomy had been secured by a blade-plate which penetrated the fracture site. No avascular necrosis developed.

(Figs. 10-A and 10-B are reproduced by permission from *Instructional Course Lectures* of The American Academy of Orthopaedic Surgeons, 1952, Vol. IX, p. 23.)

supervene. Most surgeons insist that a patient with a hip fracture walk with crutches for six to nine months. But is that long enough? The avascular necroses come on one to five years later. Why?

Have any surgeons seen avascular necrosis with sequestration and deformity develop in a patient who still walked with crutches? Stimulated by the brilliant research and the advice of our late Honorary Member, Dallas Phemister, I have insisted upon two years or more of crutch-walking for several patients with early avascular necrosis. Adequate circulation was re-established in most of the femoral heads. Perhaps prolonged support would reduce the incidence of this complication. It is worth trying! The prevention of avascular necrosis is much more desirable than an attempted cure. Why throw away the cane?

The use of an artificial femoral head is justifiable only in patients who have a relatively short life expectancy. Even in this group, most patients should prolong the usefulness of the endoprosthesis by the permanent use of a stick in the opposite hand. The surgeon should tell the patient frankly, "This makeshift hip is good for five years if you are enough of an acrobat to walk without a cane; it is good for ten years if you are smart enough to cut down on the stress that you put on this artificial joint." My figures are subject to revision when further clinical research has shown how long the average endoprosthesis will function satisfactorily.

If one must use a substitute for the upper end of the femur, the normal length of the femoral neck should be preserved, if possible, so that the abductors will work efficiently. When the abductor lever arm is reduced because of a short neck or because of valgus

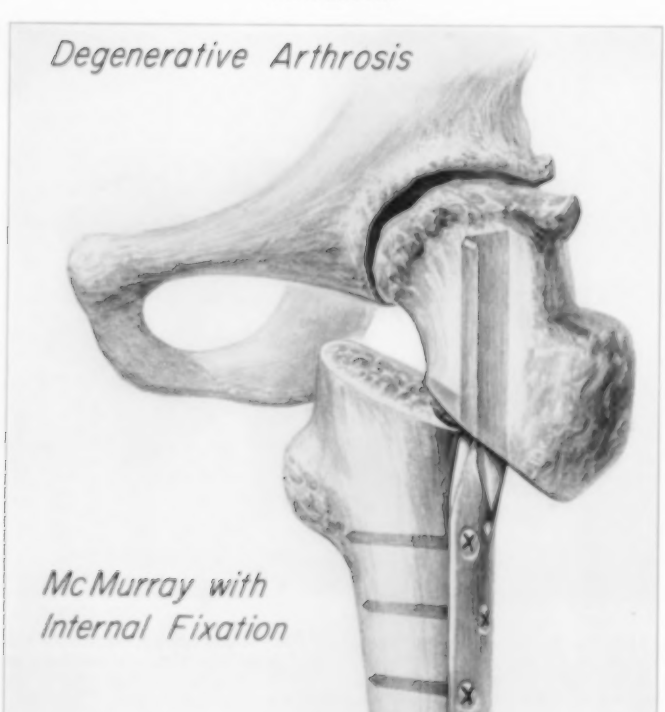


FIG. 11

The technique of the displacement (McMurray) osteotomy with straight V blade-plate fixation. A flexion deformity of 15 degrees, adduction of 25 degrees, and outward rotation of 10 degrees can be corrected without bending the blade-plate and without using one with angulation in the sagittal plane. If the proximal end of the femur is normally dense, no external fixation is necessary.

(Fig. 11 is reproduced by permission from *Instructional Course Lectures* of The American Academy of Orthopaedic Surgeons, 1952, Vol. IX, p. 23.)

position, the additional strain on the artificial hip joint must be relieved by the use of a stick. If the bone is abnormally soft or if the shaft of the endoprosthesis is loose, all surgeons will agree that the use of a cane is necessary. Is it not wise, therefore, to protect most freshly inserted endoprostheses from the start, before complications appear?

I should rather be remembered as a *thoughtful* surgeon than as a *bold* one. I submit that a well planned sequence of lesser operations with long intervals between, and the use of a cane as needed, may prove better for the patient and productive of a more desirable end result than some more heroic surgical procedure. There is a tendency among orthopaedic surgeons to exchange simple methods for dramatic treatment that will not require the use of the cane. The surgeon looks for a single, definitive, bridge-burning operation that will cure the patient completely for the rest of his life. Too often, this goal is not reached. The patient still needs the stick (or even crutches) after this heroic operation. If a satisfactory arthroplasty or reconstruction operation is performed, how much better it would be for most patients to urge the continued use of a cane in order to preserve the function of the reshaped bone by taking the strain off the hip for years, not for months only.

Degenerative arthrosis of a single hip is a good example of what I am talking about. As

the articular cartilage wears out, nature gradually produces marginal osteophytes and fibrous periarthritis that stiffens the joint. The hip that is ankylosed by nature is pulled inexorably into deformity long before motion in flexion is much limited. The patient can sit comfortably, but when he gets up to walk, the adduction-flexion deformity puts an

FIG. 12-A

FIG. 12-B

Fig. 12-A: B. H., a female, fifty years old. Roentgenogram made on October 7, 1946, showed degenerative changes in the right hip of long standing. There were increasing pain and limp. The patient could not walk fifty feet without severe pain. The Trendelenberg sign was positive on the right side. This hip was suitable for a displacement osteotomy.

Fig. 12-B: Roentgenogram made on January 4, 1956, ten years following displacement osteotomy and internal fixation. The patient walked with crutches soon after the operation. No external fixation was used. Flexion of 90 degrees was preserved so that the patient could sit. Extension and abduction were regained, permitting erect standing and walking, with only a slight limp. Weight was borne partially on the medial projection of the distal fragment, thus reducing the force on the hip [3]. Note the reestablishment of the joint interval. In ten years, there had been no worsening of the degenerative changes seen in the roentgenogram illustrated in Fig. 12-A.

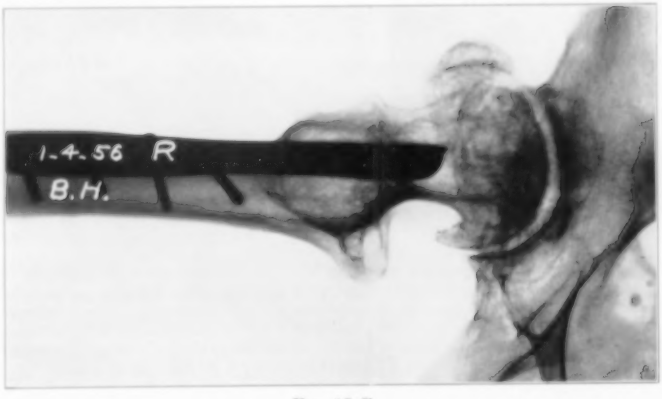


FIG. 12-C

Roentgenogram made on January 4, 1956. The joint interval looks even better in this lateral roentgenogram. It is important that the proper alignment be maintained by internal fixation. A straight V blade-plate is now used instead of the gouge-shaped blade.

FIG. 13-A

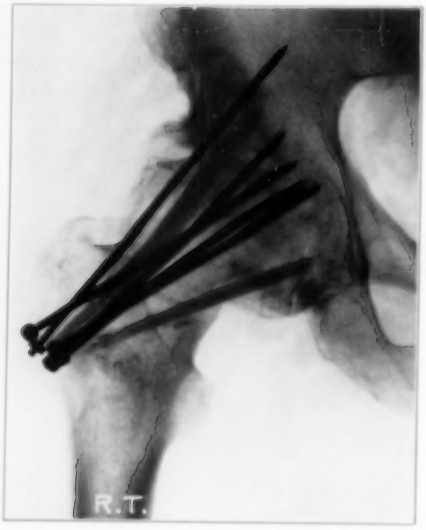


FIG. 13-B

Fig. 13-A: R. T., a male, age fifty-two. Roentgenogram made May 11, 1953, showed advanced degenerative arthrosis of the right hip. There was marked restriction of motion and there was only 20 degrees of flexion. There was an adduction-external rotation deformity. This hip was suitable for arthrodesis. The lumbar spine had gradually become accustomed to increased demands.

Fig. 13-B: A roentgenogram made July 22, 1953, two months after a pin-and-dowel arthrodesis. The hip has been brought into flexion of 30 degrees, neutral abduction-adduction, and less external rotation. In this position, the hip was nailed solidly and two grafts from the bone bank were driven across the joint line. This was done through a lateral approach without opening the hip joint.

FIG. 13-C

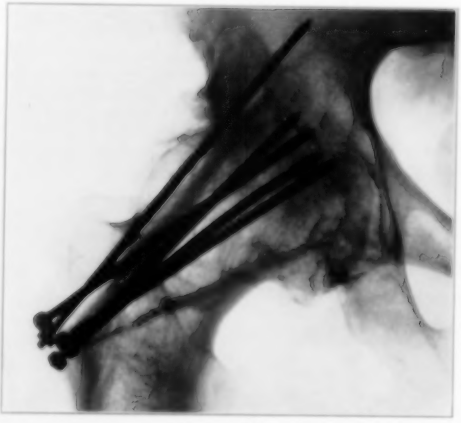

FIG. 13-D

Fig. 13-C: In the lateral roentgenogram, made on May 19, 1953 the pins are shown to be widely dispersed, giving extremely secure fixation. With a hip of average bone density, no external fixation is necessary. At the present time, one massive homogenous graft is employed at the inferior margin of the neck, together with five or six one-eighth-inch pins spread out in the superior and posterior portions of the acetabulum. The operation is satisfactory, even without the graft, but fusion is slower in becoming solid. The method should *not* be employed if there is more than 30 degrees of motion.

Fig. 13-D: Roentgenogram made on October 28, 1955, two years after fusion operation. Union of the hip was solid and the grafts were well incorporated. There was no reaction about the metal. This patient left the hospital on crutches two weeks after the operation. The hip had fused solidly in five months, but a cane was used for two months longer. Since that time, no support was necessary. An arthrodesed hip is one of the few postoperative situations that requires no cane. The patient had no back pain. The lumbar spine had gradually become accustomed to the increased mobility. Knee motion was never restricted, and the patient had the endurance which only arthrodesis can provide.

increased strain on both the ailing hip and the low back. He cannot list over in an antalgic limp, so he hurries to remove the weight from the painful hip.

A cane and an anodyne may be all that are necessary to keep him going until an arthrodesis is indicated, as I shall point out later. He may need a neurectomy or physical therapy or both, and probably he should reduce his weight. But if the pain and the deformity are excessive, how logical it is to perform a displacement osteotomy of the femur near the hip joint (Fig. 11). This operation corrects the deformity and thus relieves the pain caused by strain on the hip and the low back. Weight is borne on the distal segment[5], so that there is less pressure on the joint and greatly increased stability. Motion in flexion is preserved.

The same cut of the osteotome that corrects the mechanics of the hip relieves the arthritic ache, as was observed by J. Forbes Mackenzie of Melbourne, Australia, twenty years ago. He showed that drilling, or cutting a hole in the cortex of the bone near the hip or knee joint, relieved the pain of osteo-arthritis, often for many years. Since Mackenzie's observation, numerous new operations have been done for the relief of pain and disability. Many of the more complicated have depended for their temporary success on the simple fact that the cortex of the bone is cut near the joint.

B. H., a fifty-year-old female had a hip that was suitable for displacement osteotomy (Fig. 12-A). The Trendelenberg sign was positive on the right, and the patient could not walk fifty feet without severe pain (Fig. 12-B). Internal fixation of the osteotomized femur allowed prompt crutch-walking with partial weight-bearing. Flexion was preserved so that the patient could sit. Regained extension and abduction permitted erect standing and walking. Proper alignment as shown in the lateral roentgenogram (Fig. 12-C) is important. B. H. is well satisfied after ten years. There has been no significant change as seen in the roentgenograms. She does not tire with normal walking, and she says that she has no pain. She scarcely limps. She promises to use a cane if pain returns. I should like to have her use one now.

In such patients, there is ample hip motion in flexion in order to prevent further strain of the low back. If the motion is slowly lost over the years, the lumbar spine is gradually accustomed to increased demands. Usually the patient thinks that he sits well because he bends at the hip. He is surprised later when he is informed that he has only 20 degrees of actual flexion of the hip joint. He has been sitting by flexing his lumbar spine.

In the patient who has been carried along with a cane and conservative treatment (Fig. 13-A), or in the patient who has had a previous displacement osteotomy, enough pain may gradually develop in the stiffening hip to justify surgery. If there is only one joint involved, he may at this time be offered an arthrodesis.[2] With motion almost gone, a permanent cure is obtained by means of pin-and-dowel fixation of the unopened hip joint.

Desirable flexion of about 30 degrees is maintained. The hip is brought into less external rotation and into neutral abduction or is left in slight adduction, if the legs are of equal length. The aching is again relieved, according to Mackenzie's principle, and is permanently eliminated by obliterating motion (Fig. 13-B). The pins should be widely dispersed as seen in the lateral roentgenogram (Fig. 13-C). External support is unnecessary with bone of average density.

R. T. left the hospital on crutches after two weeks. The hip was fused solidly in five months, but he used a support for two months longer. The appearance of the hip two years later is shown in Figure 13-D.

The lumbar spine was already limber because of the gradually increasing demands put upon it by the stiffening hip joint. There was little postoperative backache and the patient was ambulatory with crutches soon after the operation. Free motion of the knee, which was much more important than motion at the hip, was maintained because the use of a cast was avoided. He was left with good function and freedom from pain. He has the

endurance which only an arthrodesis can provide. A cane is unnecessary. Even if this had been his second operation, the patient would have been hospitalized for a total of not more than four or five weeks.

A pin-and-dowel fusion does not work well when there is free motion. An attempt to arthrodese the hip ten years previously would have required an extensive arthrotomy with external fixation of the knee and back, as well as of the hip, for a prolonged period. After this enforced rest, the lumbar spine would have been called upon suddenly for activity far beyond any previous motion of these rusty vertebral joints. Pain in the low back would have been inevitable.

Arthrodesis of the hip, one of the most valuable procedures for the relief of disease, pain, or disability of the hip has fallen into disrepute in adults because of subsequent back pain in poorly selected cases. If the operative procedures are taken in logical sequence, with intermittent use of a cane, nature will help with the treatment, and arthrodesis of the hip need not be limited to children and to young adults.

Lest you think that I am just reminiscing about old-fashioned operations, let me remind you that medicine as a whole has advanced more in the last fifty years than in all preceding historic time. This is certainly true for the specialty of orthopaedics. It is with the greatest satisfaction that I review the most welcome changes that have occurred in my brief span: better treatment of fractures, particularly of the femur, the humerus, the spine, and the calcaneus, tremendous reduction of the incidence of osteomyelitis and bone tuberculosis, the diagnosis and treatment of the protruded intervertebral disc as a cause for intractable back pain and sciatica, the use of endoprostheses in selected hip disorders, and now a successful campaign against poliomyelitis.

In the near future, I look for a substantial reduction in the number of congenital deformities and in the incidence of cerebral palsy and traffic and industrial accidents. Inequalities of leg length will be controlled from the time of their appearance. Most scolioses will be prevented, and the few remaining will be intelligently and effectively treated by the average orthopaedic surgeon. The Orthopaedic Research and Education Foundation, with the help of all of us, will have a significant part in achieving these and other gains.

I hope that the next decade will see the elimination of avoidable complications in the fractures of childhood—the complications that are due to the lack of understanding of the effect of growth on fracture healing and of fracture healing on growth. This implies the knowledge that fractures in children are different. Finally I hope, that in our progressively more Utopian existence, a glorified cane will regain some of its previous popularity and will assume its proper role in the intelligent prevention and follow-up care of many orthopaedic conditions. The fallacy of our generation, "You don't need a cane", will be supplanted by the slogan, "Don't throw away the cane".

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7. Pauwels, Friedrich: Spätfolgen der Schenkelhalsfraktur. *In* Bericht über unfallchirurgische Tagung am 12. und 13. Januar 1952 in Stuttgart. Heft zur Unfallheilkunde, Heft 45. Berlin, Springer Verlag, 1953.

Dr. Sterling Bunnell entertains some of his Latin American friends at dinner during the Academy Meeting. Left to right are Lot D. Howard, Jr., Mrs. Oswaldo P. Campos, Dr. Bunnell, Renato Bomfim, W. A. Rogers, Philip H. Moore, Mrs. Bomfim, Oswaldo P. Campos, Mary S. Sherman, and Carlos Orellana.

Seated between Dr. and Mrs. Sofield on the right and Dr. and Mrs. Eggers on the left is José Valls.

Seated at Table 87 are (right to left): Mrs. Earp, Ralph K. Earp, Rufino García Rodríguez of Havana, Luis J. Iglesias of Havana, Rafael A. Arias of Havana, José Díaz Humara of Havana, J. J. Herbert of Aix-les-Bains, Irwin S. Leinbach, Carmelo C. Vitale, and Mrs. Vitale.

Top picture. Seated right to left are: Mrs. Bosworth, H. Relton McCarroll, J. Paiva Chaves of Lisbon, Dr. Frederic C. Bost, President-Elect of The American Academy of Orthopaedic Surgeons, Mrs. McCarroll, David M. Bosworth, Joseph A. Freiberg, Mrs. Dehne, and Lt. Col. Ernst Dehne.

At the left are Colmenares Pacheco, President of the Fourth Congress of the Sociedad Latino Americana de Ortopedia y Traumatologia, and Past-President Harold Boyd.

Bottom picture: Harold A. Sofield and Mrs. Sofield, Prof. José Valls, Guy Caldwell, Mrs. J. S. Barr, J. P. Chaves, and J. S. Barr. Note that as they move into the banquet one of the ladies and several of the gentlemen are carrying canes.

From right to left are: Mrs. Holmes, Duncan McKeever, Jose Sgrosso of Rosario, Argentina, Guillermo Allende of Cordoba, Argentina, Carlos Ottolenghi of Buenos Aires, Argentina, Emiliano Crespo of Guayaquil, Ecuador, Alfonso Montaigne of Lima, Peru, Frank H. Forsyth, Mrs. Forsyth, C. E. Irwin, Mrs. McKeever, and George W. Holmes.

With President and Mrs. William Green are Dr. and Mrs. G. W. N. Eggers and Guy Caldwell.

## KENNARD LECTURE IN HAND SURGERY AT THE BOSTON CITY HOSPITAL

**January 20, 1956**

The annual Kennard Lecture of the Hand Service of the Boston City Hospital was given by Dr. Michael L. Mason who discussed Dupuytren's contracture. In discussing the history, he began with Felix Plater's description, in 1614, of crispatura tendinum, and pointed out that Astley Cooper's studies, in 1822, antidated those of Dupuytren himself by eleven years. The pathology of Dupuytren's contracture is recognized to be simple fibroplasia of the palmar fascia; the etiology, however, is still obscure. Dupuytren erroneously attributed it to trauma. Among other unproved etiological factors are: the healing of minute ruptures of fibers, chronic inflammation, embryonic remains of palmar muscles, and occurrence of fibromata. Familial histories indicate that hereditary predisposition may be activated, to a minor degree, by trauma. The occasional association of Peyronie's disease (induratio penis plastica) with Dupuytren's contracture is of interest; of greater interest is the involvement of the plantar fascia, which occurs with a reported frequency varying from 2 to 20 per cent of the cases.

Contrary to a prevailing pessimism of the medical profession toward this condition, Dr. Mason emphasized that the hand surgeon should be optimistic. He feels that early operative treatment is advisable. He discussed the technique of surgery in detail, urging extensive and painstaking excision of all fascial tissue. A special danger to nerves and vessels is present during this dissection because of the tendency of the neurocirculatory bundles to be drawn out of place by the contractures.

In his discussion, the speaker acknowledged the occasional advantages of subcutaneous division of contractures in special cases, though he re-affirmed his belief in the value of early, complete operative excision, rather than postponement of operation until contractures become much harder to handle.

Previously, during the afternoon meeting, Dr. J. Edward Flynn, Chief of the Hand Service, described the transfer of tendons in the treatment of median-nerve palsy in order to supply abduction and opposition to the thumb when pinch and grasp by the thumb are weak. Tendon transfers were also described to be used in treatment of ulnar-nerve palsy when clawing of the fingers interfers with the grasping of large objects. Because of social and economic reasons, tendon transfer may be done shortly after the suturing of the radial nerve. Ten patients with tendon transfers were presented.

Dr. William F. Flynn discussed peripheral-nerve injuries. He pointed out that the decision for primary or delayed repair depended on the careful assessment of the type and the extent of the injury to the nerve and its surrounding tissues. To illustrate this principle, a group of patients was shown who had complete motor and sensory recovery, or varying degrees thereof.

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## ANNUAL JOINT MEETING OF THE WASHINGTON-BALTIMORE ORTHOPEDIC CLUB

**April 2, 1956**

At the recent joint meeting of the Washington-Baltimore Orthopedic Club, the following papers were presented:

Plastic Arthroplasty of Joints using Ivalon Sponge
Milton C. Cobey, M.D., Washington, D. C.

Cortical Abscesses in Bone
I. Peter Kenmore, M.D., Washington, D. C.

Techniques of Obtaining and Storing Tissues from Cadavera (motion picture)
Commander George Hyatt, United States Navy Medical Corps

Restoration of Knee Joint Motion following Excision of Intra-articular Adhesions
Carl Berg, M.D., Washington, D. C.

Use of Naval Bank Bone for Restoring Spine Stability after Complete Cervical Laminectomy in a Child
William J. Tobin, M.D., Washington, D. C.

Stabilization of Proximal Interphalangeal Joint following Old Hyperextension Injury by Means of a Volar Criss-Cross Tendon Graft
John P. Adams, M.D., Washington, D. C.

**HERMAN CHARLES SCHUMM**

**1889–1955**

Herman Charles Schumm, one of the pioneers of orthopaedic surgery in Wisconsin, died at the Oconomowoc Hospital on December 21, 1955, after a brief illness.

Herman Schumm, the son of a regular Army officer was born on November 23, 1889 at Fort Hamilton on the New York coast. Although he lived most of his life in the Midwest, he was educated in the East, spending seven years at the University of Pennsylvania, where he received his academic and medical degrees. During his last year in medical school his father, who was the Commandant of Fort Wadsworth on Governor's Island, New York, died.

Dr. Schumm's father, Col. Schumm, was born and was brought up in the vicinity of Sauk City, Wisconsin. One of his boyhood friends was Dr. Albert Ochsner, and the latter's interest in the younger Schumm influenced him to take his internship at the Augustana Hospital in Chicago, where he received his surgical training under Dr. Ochsner. Here he met his wife, the former Sarah Johnson of Escanaba, Michigan. She survives him, as do two sons, Herman III and David.

During World War I, Herman Schumm served in Austria with an American Red Cross Surgical Relief Unit from Chicago headed by Dr. Eastman. He subsequently served two years as Lieutenant and Captain in the Army Medical Corps with the Ochsner Base Hospital Unit at Nantes, France.

Following the war, after being stationed briefly at Fort Sheridan, Dr. Schumm came to Milwaukee where he became an associate of Dr. Frederick J. Gaenslen; this association prevailed until the latter's untimely death in 1937.

Dr. Schumm was a conscientious and indefatigable worker who loved his work, his patients, and his friends. He loved the close personal contact which an orthopaedic surgeon has with his patients and was particularly interested in children's work. He was fond of the out of doors and of hunting and sailing; he always liked to have his friends about him. In late years his health failed him, but he kept on with his work and with his many associations.

Among his many contributions to medical literature were a report of an operative procedure for arthrodesis of the hip in children and an analysis of the Schanz osteotomy for fractures of the neck of the femur.

For many years he was Attending Surgeon at Milwaukee County Hospital and Milwaukee Children's Hospital; in later years he was made senior consultant at these institutions.

At the time of his death, he was Clinical Professor of Orthopaedic Surgery at Marquette University, Associate Professor of Orthopaedic Surgery at the University of Wisconsin, a Fellow of the American College of Surgeons, a member of The American Orthopaedic Association, The American Academy of Orthopaedic Surgeons, Clinical Orthopaedic Society, Wisconsin Orthopaedic Society, The International Society of Orthopaedics and Traumatology, Milwaukee Surgical Society, and The Milwaukee Academy of Medicine. He was Consultant Orthopaedist to the U. S. Veterans Hospital at Wood, Wisconsin, Attending Surgeon at Columbia Hospital and Milwaukee Hospital in Milwaukee and at Oconomowoc Hospital at Oconomowoc, Wisconsin.

Dr. Schumm served as Vice-President of The Academy of Orthopaedic Surgery in 1942 and in the same capacity for The American Orthopaedic Association in 1951.

His primary interest was his association with the Orthopaedic Departments of both the University of Wisconsin and Marquette University.

Herman Schumm, with his amiable personality and quiet manner, will be greatly missed by his colleagues and friends both here and abroad.

# News Notes

The Sixty-Ninth Annual Meeting of The American Orthopaedic Association will be held at Banff, Alberta, Canada, June 20 to June 23, 1956, under the presidency of Dr. Paul C. Colonna.

## AMERICAN BOARD OF ORTHOPAEDIC SURGERY

Final date for filing applications for the Part II Examinations to be given in January 1957, in Chicago, is August 15, 1956. Application should be made to the Secretary, Dr. Sam W. Banks, 116 South Michigan Avenue, Chicago 3, Illinois.

The next Annual Meeting of the **Western Orthopaedic Association** will be held in Phoenix, Arizona, from October 30 to November 3, 1956, under the presidency of Dr. James Lytton-Smith.

## EXCHANGE FELLOWSHIPS

The Exchange Fellowships Committee of The American Orthopaedic Association invites application from American orthopaedic surgeons for the four fellowships to visit Great Britain in the spring of 1957. All applications must be in the hands of the Committee by December 1, 1956; any submitted after that date cannot be considered. General requirements for each applicant are:

1. American citizenship;
2. Successful completion of Part II of the American Board of Orthopaedic Surgery Examinations;
3. The applicant must be under forty years of age as of December 1, 1956.

Application forms and other details of application will be furnished upon written request to the Committee Chairman, Dr. J. Neill Garber, 806 Hume Mansur Building, Indianapolis 4, Indiana.

**The National Society for Crippled Children and Adults** will hold its annual convention October 28 to 31, 1956, in Washington, D. C. Dr. Walter Blount, immediate Past-President of The American Academy of Orthopaedic Surgeons, is among the principal speakers scheduled for the general sessions planned for the mornings of the convention. Dr. James B. Johnson, Newark, Ohio, is Chairman of the 1956 Convention.

## KAPPA DELTA AWARD

The Committee on Scientific Investigation of The American Academy of Orthopaedic Surgeons announces that all manuscripts which are to be entered for the Kappa Delta Award, which is presented annually for the outstanding scientific contribution in the field of orthopaedic surgery, should be forwarded to the Chairman of the Committee, Dr. Donald B. Slocum, 132 East Broadway, Eugene, Orgeon. Since the winner of the Kappa Delta Award will present his paper before the General Membership of the Academy at the Annual Meeting in January 1957, it is necessary that all manuscripts be received by August 15 so that they may be properly evaluated and forwarded to the Executive Committee of the Academy for approval. This is a departure from previous years when final selection was not made until October 1.

The Eleventh Congress of the **Sociedade Brasileria de Ortopedia e Traumatologia** will be held in Porto Alegre, Brazil, from July 8 to 14, 1956, under the Presidency of Dr. Elias José Kanan. Subjects which have been announced for discussion during the meeting include: Lumbar-Sciatica Resulting from Disc Herniation; Metabolic Diseases of the Skeleton; Surgical Treatment of Osteochondritis; Treatment of Fractures of the Knee.

The **Texas Orthopaedic Association** held its Annual Meeting April 23, 1956, in Galveston, Texas. The following were elected to office:

*President:* John J. Hinchey, M.D., San Antonio, Texas;
*Vice President:* Lawrence Griffin, M.D., Austin, Texas;
*Secretary-Treasurer:* Margaret Watkins, M.D., Dallas, Texas.

Dr. Rex L. Diveley, Kansas City, Missouri, the guest speaker, was elected to Honorary Membership.

**The Women's Medical Association of New York** offers the **Mary Putnam Jacobi Fellowship** to a graduate woman physician, either American or foreign. The fellowship will begin October 1, 1957, and will amount to $2,000, $1,000 being available October 1, 1957. The recipient of the fellowship will be expected

to make a report to the Committee at the end of the fourth month, following which the second $1,000 will be awarded, subject to the approval of the Committee. The fellowship is given for medical research, clinical investigation, or postgraduate study in a special field of medicine. Application for this fellowship must be filed with the Secretary of the Committee by October 1, 1956 and will be acted upon by January 1, 1957. Further information and application blanks may be obtained from the Secretary, Ada Chree Reid, M.D., 118 Riverside Drive, New York 24, N. Y.

The first **Regional Conference of the Orthopaedic Section** of the **Association of Surgeons of India** was held in Calcutta on April 14 and 15, 1956.

The first **Pan-American Convention of the Willis C. Campbell Club** was held in Havana, Cuba, November 30, December 1, 2, 3, and 5, 1955. The meeting was attended by many members of the staff of the Campbell Clinic, Memphis, Tennessee, including the Chief of Staff, Dr. J. Spencer Speed.

## LETTER TO THE EDITOR

*To the Editor:*

I have read in the October 1955 issue of *The Journal* (pages 971 to 977) Dr. Lippman and Dr. Grew's paper on "Neurogenic Arthropathy Associated with Diabetes Mellitus. Review of the Literature and Report of One Case in a Juvenile Diabetic". It seems to me that it is a very good paper. Nevertheless, since they include in the title "with a Review of the Literature", I would like to report a case published in *La Prensa Médica Argentina:* Artropatia Diabética; artropatia neuropática en les diabéticos by I. Blumenfeld and C. A. Campos, Vol. 38, pages 2722 to 2728, October 1951.

In this paper we reported the case history of a patient with ankle and foot involvement upon whom we operated. A report of the pathology was included.

I would appreciate very much the publication of this letter in order to complete the bibliography on the subject.

I. Blumenfeld
Av. Calla 626, 4o
Buenos Aires, Argentina

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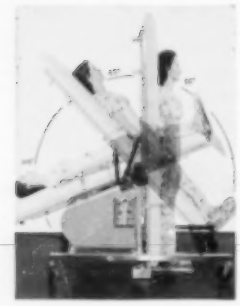

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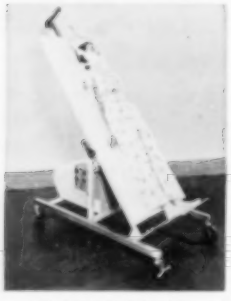

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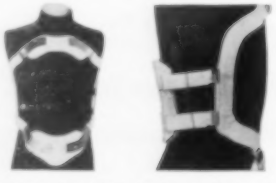

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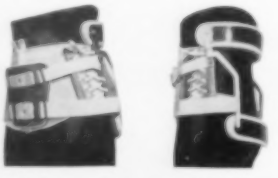

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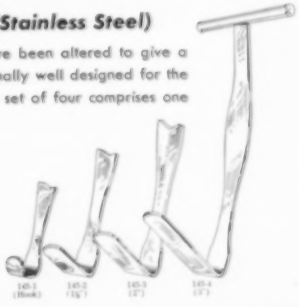

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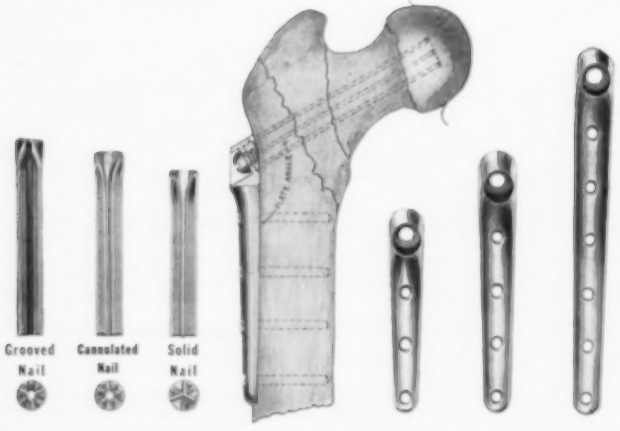


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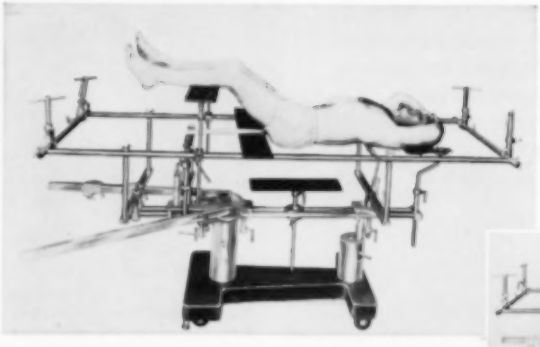

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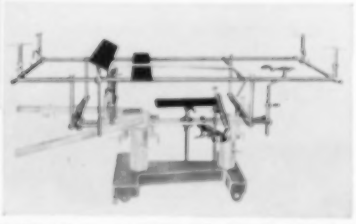

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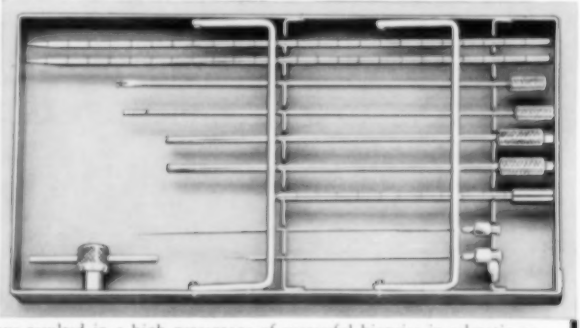

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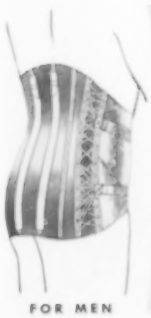

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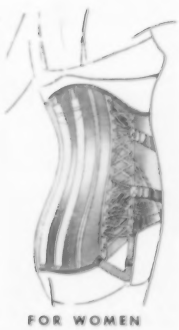

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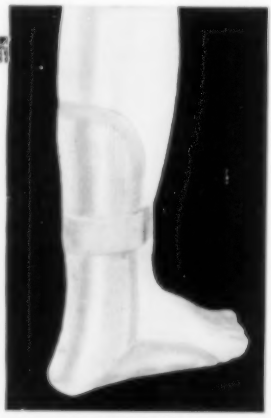

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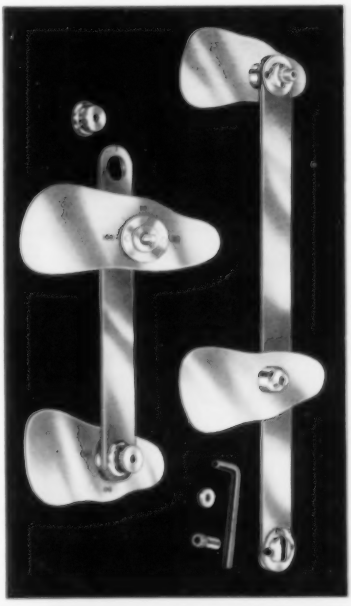

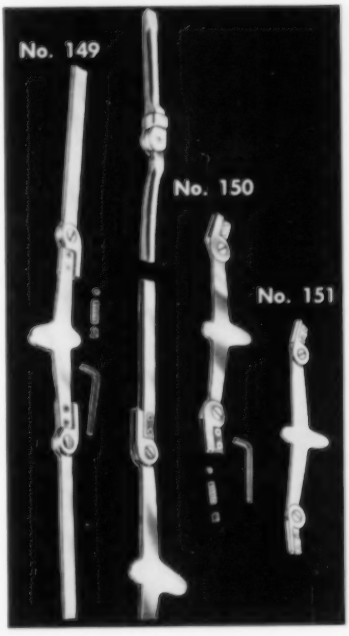


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